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86th Congress
2d Session } JOINT COMMITTEE PRINT

BACKGROUND MATERIAL FOR THE REVIEW OF THE INTERNATIONAL ATOMIC POLICIES AND PROGRAMS OF THE UNITED STATES

REPORT

FROM THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

VOLUME 5

OCTOBER 1960

Published for the use of the Joint Committee on Atomic Energy

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BACKGROUND MATERIAL FOR THE REVIEW

OF THE

INTERNATIONAL ATOMIC POLICIES AND PROGRAMS OF THE UNITED STATES

By

ROBERT MCKINNEY

LETTER OF TRANSMITTAL

OCTOBER 1960.

Hon. CLINTON P. ANDERSON,
Chairman, Joint Committee on Atomic Energy, Congress of the United States, Washington, D.C.

DEAR MR. CHAIRMAN: On September 14, 1959, you requested that I undertake for the Joint Committee on Atomic Energy a review of the international policies and programs of the United States relating to the peaceful uses of atomic energy.

The review has been completed. I take pleasure in transmitting to you herewith my report, together with the background material assembled in the course of its preparation.

I am grateful for the cooperation so freely given by governments and officials in public and private life throughout the free world, whose cooperation was essential to the conduct of this review. The assistance of the many departments and agencies of the executive branch of the U.S. Government was invaluable, as were the contributions of many private citizens and industrial organizations in the United States. I am particularly grateful for the support of the Joint Committee, its staff, and the Library of Congress.

Without the administrative assistance made available by the Atomic Energy Commission, and all the other support received, the conduct of this review would have been impossible. I should add, however, that the judgments, conclusions, and recommendations contained in Volume I of this report are those of the author, and are not necessarily those of the Joint Committee on Atomic Energy or of the executive branch of the Government.

Furthermore, although the material contained in the Background Volumes was considered by the author in the preparation of Volume I, it should not be assumed that its publication is intended to imply that the statements or opinions contained therein are subscribed to in the review or that their correctness is underwritten.

I appreciate this opportunity to serve you and the Joint Committee.

Respectfully,

ROBERT MCKINNEY.

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FOREWORD

Purpose

The Joint Committee on Atomic Energy has requested that facts and judgments pertaining to the current status of the international policies and programs of the United States as they relate to the peaceful uses of atomic energy be brought together, appraised, and evaluated in relation to their original premises and purposes, and that those alternative courses of action which appear to be open to those responsible for the formulation and execution of atomic policies and programs for the future be explored.

Such a review is now timely. Searching reexamination has already begun in many quarters in many nations as to whether competitive civilian atomic power is in itself an achievable near-term objective, or whether the extensive technical capabilities devoted thereto might better be directed to other purposes. The various international instruments and institutions in the peaceful atomic field and the broad objectives underlying their creation have come into question.

Other developments which make a current reappraisal timely include:

(1) The growing body of experience with more precise estimates and actual costs of reactor construction and operation both at home and abroad;

(2) Significant changes in the supply and the demand both of fossil fuels and fissionable materials;

(3) Changed prospects for an effective international safeguards system;

(4) Changed prospects for disarmament and for cooperation with the Soviet Union;

(5) Public concern with radiation hazards arising from reactor operation and the disposal of radioactive wastes.

Current pessimism about the outlook for peaceful atomic applications, especially for civilian atomic power, may be as much a product of misunderstanding as was yesterday's overoptimism. Certainly, the inherent realities of what atomic energy can do for mankind are no less today than 6 years ago. Undue pessimism could do irreparable damage. It is important, therefore, that the nations of North America and Western Europe most advanced in atomic technology resurvey their positions and, if necessary, reset their courses.

Scope

The review embraces U.S. relationships with industrialized and less-developed countries, with allied countries, and with Communist-dominated countries.

In order to assemble the review in the most useful form, studies have been made of the current and prospective status of civilian atomic power, and of other peaceful atomic applications; of informed

energy-resource estimates and energy-demand forecasts; and of the evolution of the international policies and programs of the United States in the peaceful atomic field.

While the review and evaluation are concerned with all geographic areas and all atomic applications, U.S. relationships with other nations of North America and Western Europe advanced in atomic power have received the greatest attention in this presentation so that it could be organized within manageable proportions. No implication of relative priorities as to geographic regions or programs is to be construed. The importance of U.S. relationships with other areas of the free world, including the less developed countries, and with the Soviet Union is evident.

Method

Several mechanisms have been employed to insure objectivity and to uncover as many relevant details as possible, both of fact and policy consideration. Reports on the status and prospects for atomic science and technology have been reviewed, evaluated, and summarized by recognized experts, selected on the basis of competitive proposals and working under contract to the U.S. Congress. Energy resources estimates and demand forecasts have been reviewed, evaluated, and summarized by a competent authority under contract to the U.S. Atomic Energy Commission. These data have been prepared without intervention or dictation from those conducting the review or others.

More than 200 interviews have been conducted by the review staff in 14 European countries, including the Soviet Union and Poland. Through these interviews, judgments were obtained from individuals concerned with the direction of national atomic programs and laboratories, and from key officials of the principal international atomic organizations.

Requests were addressed to the Soviet Union, paralleling those addressed to other nations, and conversations were conducted in the U.S.S.R., in Western Europe, and in the United States with high Soviet officials in connection with the review and the Soviet Union's contribution thereto. The only written material provided in reply by the U.S.S.R., however, was the Russian text of a speech by V. S. Emelyanov, previously published in English in the proceedings of the 1958 United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva.

Judgments were also obtained both at home and abroad from responsible government and industry officials outside the atomic field concerned with formulation of broad national and international economic, financial, and political policies, with scientific and industrial planning, and with related commercial activities. These outside judgments were obtained in order to place atomic energy in the perspective of overall national and international objectives, and to avoid confining the review to narrow atomic areas.

The assembled factual reports, evaluations, and opinions have been considered and weighed in the light of discussions with senior officials of the U.S. Department of State, the U.S. Atomic Energy Commission and the Joint Committee on Atomic Energy, and with their opposite numbers in North American and European countries advanced in atomic technology.

All of the specially prepared reports, memorandums, and evaluation reports assembled and carefully considered in the course of the review are reproduced in volumes 2 to 5 of this report, entitled "Background Material." Data and judgments obtained on a private basis have not been summarized, except where specific permission was obtained. Other reports and data previously published and used in the course of the review are referenced in the background material volumes and are available to the public.

BACKGROUND MATERIAL FOR CHAPTER 4: OTHER PEACEFUL ATOMIC APPLICATIONS

STAFF NOTE.—The following paper was prepared for the Review Staff by Dr. John C. Bugher of the Rockefeller Foundation.

MEDICAL USES OF ATOMIC ENERGY

John C. Bugher, M.D.
Rockefeller Foundation

Radiation is a highly potent biological agent. Inevitably there is both concern about the possible injury which may result from excessive radiation exposure and great hope that radiation and radioactive substances may provide highly effective tools for the advancement of both public and individual health.

Medical and public health requirements are by no means the same in all geographical regions. Large sections of the world's population, especially those in the tropics, find that their principal problems of health deal with infectious disease and nutrition. All other medical considerations are secondary in such regions. On the other hand, in nearly all of the so-called "developed" countries, the relative importance of both infectious disease and malnutrition has declined over recent decades. With the resultant extension of the life span, there is increasing preoccupation with degenerative diseases, those whose emergence above the clinical horizon may require a long span of time. Children who in former times would have died from infectious disease live to become productive adults. We find ourselves increasingly concerned about diseases of the later decades of life, such as cancer and heart disease.

In addition, we find that the extension of life span in the industrial societies is also frequently accompanied by the

widespread contamination of the environment by substances of uncertain degree of toxicity. Among these are radioactive substances resulting from atomic energy activities.

Eventually, in the advanced countries among which there is the most rapid development of the utilization of atomic energy, we may anticipate an increasing concern with the public health implications of the subjection of large populations to small quantities of radioactive materials. One of the most urgent problems confronting all nations jointly is that of determining quantitatively the biological effects of small doses of radiation delivered over a long period of time. Adequate studies involve the observation of large populations, whether of animals or man and necessarily must extend over substantial periods of time. Better results from the animal segment probably can be achieved through joint planning of replicate experiments to be conducted in several countries simultaneously.

In parallel with experimental studies, there is opportunity to evaluate the effects of exposure to high natural background radiation on substantial human populations over many generations. There exist populations of the order of 100,000 persons in regions which for centuries have been exposed to gamma radiation of 10 to 50 times the usual background intensity. Epidemiological research would be of the greatest value to the entire world in providing solid data upon which to base the future criteria of acceptable radiation exposure.

Radiation therapy of cancer is already highly developed and while there are special advantages in using the gamma radiation from cobalt-60 and cesium-137 in external therapy, it is likely that further major developments in the therapeutic uses of radiation will be from the generation of powerful radiations within the cancer cell itself. A good example is the release of energy when the boron-10 atom captures a neutron. At the moment, this new technology will require much more study before a value judgment may be made. If it fulfills its promise, then nuclear reactors will become invaluable tools in the hospitals of the future.

The shifting age composition of the population in the industrially advanced countries will require far more emphasis on the recognition of degenerative disease long before it has become manifest by present clinical standards. The process of aging actually begins at birth and proceeds by subtle stages as life advances. Much of the degenerative disease of the middle decades is of the nature of the acceleration of aging processes which normally become obvious in the later periods of life. Examples are many, among them being arteriosclerosis, disturbances of mineral metabolism, and even some forms of cancer.

The recognition of early degenerative changes becomes of crucial importance if a new version of preventive medicine is to

become effective. Intracellular enzymatic reactions must be measured quantitatively in the patient without injury to him. This can only be accomplished by inserting radioactive atoms into the molecules of essential compounds that are involved in each enzymatic step. By such means, it has already been found that there are genetically determined differences in the ways in which people metabolize sugar. The employment of carbon-14 tagged sugars for this purpose is still a pure research procedure but this and many similar procedures will, in the course of the next few years, become widely employed in diagnostic medicine because they yield information about the patient which can be obtained in no other way.

Diagnostic procedures of the general character under discussion are actually a further development of the techniques of research which have already revolutionized biology and biochemistry. The advances in biochemistry of the last ten years probably exceed the total of previous decades. The acceleration in the acquisition of new knowledge has, in large part, been the result of the general availability of radioisotopes. As understanding of the fundamental nature of life processes is acquired through broad areas of research, special techniques become available for diagnostic purposes in medicine and eventually become routinely utilized.

To a modest extent, diagnostic procedures based on isotopic techniques have already altered the character of modern medicine. Radioiodine in various combinations is widely employed in the differentiation of thyroid diseases and in clinical studies of both the formation of the blood and the dynamics of its flow. Measurement of such quantities as total and intercellular body water, the amount of fat, the blood volume and total body volume are easily performed. The assimilation and metabolism of fats, the production of hemoglobin and the rates of replacement of blood cells are further examples of areas of diagnostic interest where the isotopic procedures are now widely employed.

A further example of an entirely new field of diagnosis is the measurement of the radioactivity of an entire individual by surrounding him with a special apparatus capable of detecting all radiations emitted from his body. The movement of a radioactive isotope which may have been introduced in extremely minute amounts may be followed with the greatest sensitivity and precision. Methods based on this approach have already been invaluable in the diagnosis of various kinds of anemia and in the recognition of unusual metabolic patterns for trace elements such as cobalt and molybdenum.

Diagnosis may be advanced through activation analysis of biological specimens. Here a nuclear reactor is usually employed so that certain elements may be made radioactive and thus determined quantitatively by measuring the amount of induced radioactivity.

A number of trace elements of importance in metabolic processes may be determined quickly by this method.

These and other highly sensitive procedures which can be used without harm or inconvenience to the patient indicate that the greatest application of nuclear energy in medicine will be in the diagnostic field. Herein lies the most attractive prospect for the recognition of degenerative changes long before they can become apparent in the form of gross damage to the patient. These must be the tools of the preventive medicine of the future and increasingly become the focus of research in all modern medical centers. The new methods must be based upon both biochemistry and physics and require the coordinated application of these disciplines to the special needs of the human patient.

As was indicated earlier, the underdeveloped countries find their outstanding medical problems to be infectious disease and malnutrition. The study of the nutritional diseases, to be effective, requires the ready availability of special compounds tagged with radioactive isotopes. Their production must generally be accomplished in the great centers for nuclear research; in other cases, a small reactor close at hand is required. In either case, the actual clinical investigations must be carried out in the regions where the problems are encountered. It must be emphasized that real progress in this field presupposes the establishment of a sound base of medical education and research in the underdeveloped countries as rapidly as the pace of human growth and development will permit.

The outstanding importance of infectious disease in the underdeveloped countries emphasizes the need for effective public health measures. Many of the crippling diseases are insect borne, insects whose biology is very incompletely known. Radioactive tagging of insects has been shown to be the most efficient method of determining such important characteristics as flight patterns and range, life span, and population characteristics.

In a different relationship, gamma radiation (in some instances beta radiation) may be used to sterilize male insects to be released in the wild environment where they will mate with females whose progeny thereafter will be deficient. By radiation of males the fly-producing screwworm in cattle has been eliminated in two geographic regions and it is probable that the method may be applied to the eradication of the tsetse fly which carries the trypanosome of sleeping sickness in tropical Africa.

By these and numerous similar procedures, radioactive materials may be used to accelerate the advance of public health measures and in special instances to affect the prevalence and perhaps to eradicate diseases which in some areas are effective barriers to social and economic progress. The research required, in nearly every instance, involves the participation of major centers for nuclear research in programs conducted in the countries where the problems are found.

All of these applications of nuclear energy in medicine and public health involve research which cuts across several disciplines and calls for the coordinated labors of scientists in several geographic areas simultaneously. The objectives are to anticipate the medical problems of both developing the mature societies and, early recognition of disease by application of the proper preventive measures made possible through its progress.

May 9, 1960

STATUS AND PROSPECTS FOR DIRECT CONVERSION OF ATOMIC POWER

STAFF MEMORANDUM

(Based on discussions and interviews with individuals active in development of direct conversion devices)

A. Device for Converting Decay Energy of Fission Products into Electrical Energy

Although about 5% of the total energy released in fission is contained in the excitation of the fragments and appears primarily as beta and gamma radiation, only a small fraction of this can be practically available.

Only those products which have a reasonably long life (perhaps greater than 100 days), adequately high-specific activity (more than 0.001 watts/gram), and are relatively easily converted to heat sources (beta rather than gamma emitters) can be considered. This restriction, coupled with relatively low efficiency of conversion to electrical energy, probably less than 10%, limits the application to very special purposes and is in no sense a significant economic incentive for overall utilization of the fission process.

As far as can be seen at this time, such applications may well approach costs of the order of $5/kwh over a 10-year period and, therefore, are of interest only in those cases in which small amounts of power, in the order of 1 KW, are required for special reasons of compactness, light weight, relatively long life, and freedom from maintenance.

For these reasons and the fact that special applications are most apt to result from normal commercial incentives, it is not recommended that such items be made a part of any international support.

B. Direct conversion methods for utilization of fission fragment kinetic energy in production of electrical energy

1. Charged fragments from fission which have high kinetic energies are sources of power in principle. However, the fact that fragment energies are of the order of 100 million electron volts and that the charge per fragment is of the order of 20 electron charges poses grave technical problems to this type of direct conversion of fission energy. The high voltage is disadvantageous to insulation; the magnitude of charge requires collection of fragments, usually only one-half at best, over a large area to obtain interesting total currents, and this is inconsistent with interesting power densities.

As a result, one does not see any serious attention being given to this approach.

2. In contrast to the above, there are several avenues which, while not as direct, do offer some promise in eliminating the conventional thermo-mechanical cycle in electric power generation. They all depend on the initial conversion of fission energy to thermal energy, but differ in the final step to electrical energy. They are—

a. Conversion of thermal to electrical energy by use of the thermo-electric effect in metals and semiconductors: For basic reasons, metals have low conversion efficiency. Semiconductors are better in principle but laboratory efforts so far suggest conversion efficiencies of not much greater than 10%.

b. Thermionic devices: Both vacuum and gas diodes are under investigation as converters. Small, close-spaced vacuum diodes have been operated at efficiencies of 2%, although much higher efficiencies are possible theoretically.

The gas diode, also called the plasma thermocouple, has been operated with fission heating of the cathode at Los Alamos. An electrical output of 30 watts, 40 amperes was obtained in this experiment.

Low voltage direct current is a characteristic of these cells but, nonetheless, serious attention is being given to their development.

Ultimate success of these methods will depend on development of high temperature, radiation resistance heat sources. In this respect the problems are not unlike those of high temperature reactor fuel elements with added requirements in electrical properties.

c. Magneto-hydrodynamic method: At sufficiently high temperatures gases can be dissociated and the resulting plasma of electrons and ions used for direct generation of electrical power if such a plasma is moved in a magnetic field. Thus, instead of a working fluid, such as steam, being used to convert thermal energy to the motion of an electron gas confined to a conductor to produce electricity by the Faraday effect, the working fluid moving in a magnetic field becomes the generator itself.

Here again, high temperatures (3000° F.) are required and the fission source must be capable of withstanding thermal and atomic radiation effects.

In all three of these direct-conversion devices the experimental work it too recent and too incomplete to make a satisfactory evaluation. It may be that the problems are not appreciably greater than those of constructing more usual fuel elements to operate in a similar temperature range. These methods could be of some advantage in extracting power from regions of higher power density than can be done with conventional working fluids. However, except for possible uniqueness of the direct heating of a cathode containing fissile material, most of these methods could be applicable to conversion when the heat source is derived from conventional fuels. Their nature at this time suggests special applications rather than any major contribution to economical, large-scale power production. As such, they can hardly be expected to be significant in any U.S. objectives, national or international, which are directed toward the latter goal.

MAY 12, 1960.

STATUS AND PROSPECTS FOR NONPOWER APPLICATIONS OF ATOMIC ENERGY

NOTE BY THE REVIEW STAFF

A series of requests were made to the Atomic Energy Commission and other Government agencies for short summary status reports on various nonpower applications of atomic energy. These reports are reproduced in this section of background material. As with other major technical aspects of the study, an independent appraisal of this material, and the subject matter it represented, was conducted. This appraisal report, by Battelle Memorial Institute of Columbus, Ohio, also appears in this compilation of background information.

The following invitation was sent to three firms qualified to perform the summary and evaluation services concerning the basic data for this chapter of the study. The night letter of invitation is reproduced below, in order to set forth the scope of the work actually undertaken by the selected contractor.

[Night letter]

DECEMBER 29, 1959.

Joint Congressional Committee on Atomic Energy invites you to propose on fixed-price letter-contract in connection with Review of International Policies and Programs of the United States being conducted by Robert McKinney, described in Forum Memo, November, page 32. Copy of Committee press release, descriptive speech, and Report outline forwarded to you today.

Contract scope as follows: receive and determine adequacy of coverage of reports relating to peaceful noncentral-station power applications being prepared by other organizations for the Review and identify any significant areas of application not covered and fill in from existing or readily prepared reports and other sources; evaluate, including by interviews or seminar with senior informed scientists, engineers and industrialists to the extent required, the validity of the estimates of present status and forecasts of prospects for each of the classes of noncentral power applications covered; and summarize evaluation and set forth conclusions and independent appraisal. End of work scope.

Status and prospect reports are scheduled for submission to the Review Group and the contractor by February 15. Summary and conclusions requested are to be available not later than April 15 in 25 copies. Letter or telegraphic proposal due by 3:00 p.m., January 7, delivered either c/o U.S. Atomic Energy Commission, Room 1151, 1717 H Street, NW., Washington, D.C.; or c/o U.S. Mission to United Nations, Room 1927, 2 Park Avenue, New York City. State briefly where the work will be done, how work scope will be performed, the senior person responsible, estimated number of professional individuals, by profession, to be involved, and estimated number of manhours of professional time required. Breakdown of cost to Joint Committee of interest, but not required.

Mr. McKinney's staff available to answer questions by telephone in New York on MUrrayhill 3-6810, Ext. 291, on January 4 and 5, from 9:00 a.m. to 5:00 p.m.; and in Washington on HAzelwood 7-7831, Ext. 5761, on January 6, from 2:00 to 6:00 p.m.

Letter contract expected to be let directly by Joint Committee. Selected contractor will be notified on or about January 15.

JAMES RAMEY,
Executive Director, Joint Committee on Atomic Energy, U. S. Congress.

THE APPLICATIONS OF ATOMIC ENERGY OTHER THAN CENTRAL-STATION POWER GENERATION

A Technical and Economic Analysis of Their Role in the U. S. International Atomic Energy Programs

for

THE JOINT COMMITTEE ON ATOMIC ENERGY
UNITED STATES SENATE
WASHINGTON, D. C.

by

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April 18, 1960

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THE APPLICATIONS OF ATOMIC ENERGY OTHER THAN CENTRAL-STATION POWER GENERATION

A Technical and Economic Analysis of Their Role in the U. S. International Atomic Energy Programs

SUMMARY OF MAJOR CONCLUSIONS

This review was made for the purpose of providing an analysis of the technical and economic status of atomic-energy applications, at the request of those charged with the review of the United States international programs on atomic energy. The conclusions reached from this analysis must be viewed in this framework, for their scope has been rigorously limited in the following ways:

(a) It is exclusively a technical and economic analysis – social and political factors are not considered. Therefore, atomic-energy applications are necessarily judged solely by the material contribution they might make to the welfare of nations.

(b) Since it is a technical and economic analysis, it is possible to draw conclusions about possible utility only when there is enough information about an application of atomic energy for a meaningful evaluation to be made. For far-off applications, only the research needs can be discussed.

(c) Each atomic-energy application is considered individually, without comparison to other applications. The benefits of agricultural applications of atomic energy differ from those of nuclear propulsion, both in kind and in the regions of the world where they will have most benefits. Therefore, the decision that one, rather than the other, should be emphasized in our international support programs

on atomic energy cannot be made solely on technical and economic bases: such decisions depend more importantly on social and political bases.

(d) Since most of the applications of atomic energy are not yet fully developed, the discussions center largely on research and development prerequisite to practical application.

The major conclusions reached during this study, given below, should be considered with these restrictions kept firmly in mind.

(1) Applied research and development are the types of scientific activity which lead most directly to practical benefits that will improve the welfare of other countries. Such activities seem to be the only ones capable of improving the status of underdeveloped countries. Basic research, which can both stimulate and facilitate applied research, can best be done by the well-developed countries. However, even for such countries with the exception of the United States, it appears that the practical benefits achievable through research of all kinds would be realized sooner and to a greater degree through stimulating applied rather than basic research.

(2) The most appropriate application of nuclear reactors, as a source of heat energy, is for central station power generation of electricity. The other uses of heat from nuclear reactors are less significant applications for the following reasons.

(a) In selected instances, low-temperature applications of reactors for generating process heat appear to offer promise in competition with conventional fuel. However, the number of such cases is small, for while process heat applications

in the aggregate use more fuel than central-station power generation, the fraction of these replaceable by atomic power is small. A large fraction of the process heat requirements involve high-temperature heat which reactors cannot yet supply, or by-product heat which otherwise would be wasted. In addition, process heat units are frequently small, have a poor load factor, or are subject to rapid amortization, and, in such situations, reactors are at a greater disadvantage relative to conventional boiler units fired with fossil fuels.

(b) Space-heating applications are especially unsuited to reactors, since all the disadvantages of process heat applications apply, and with even greater force.

(c) The purification of saline water appears to be an application which is especially well suited technically to nuclear reactors. However, problems other than those involving reactors are more important to economic feasibility. While the ultimate use of reactors in this application would perhaps never be large, compared to electric-power applications, it may be a very useful application to some of the countries of the world.

(d) Reactors appear to have advantages in special circumstances for ship propulsion. The major problems needing solution do not seem to be problems of reactor application. Furthermore, in large part, reactor technology developed from research on central-station power applications will be applicable to the engineering of reactors for ship propulsion.

Thus, the research and development still needed on reactors should be focussed on the central-station power application. The studies

needed are extensive, and deal primarily with the problems of fuel cycle cost and decreases of the capital cost of nuclear reactors. It is evident that much research will be needed before economic solutions to these reactor problems will be found. Such research might be carried on wherever suitable facilities and scientific abilities can be found.

Economic solutions to these problems will simultaneously provide solutions for the reactor applications discussed in this report. In addition to such research, studies of some of the special problems of reactor types discussed in this report merit consideration. Such studies might deal with the application of nuclear power for saline-water purification, the special problems of marine propulsion, the study of unique ways to use nuclear power in this application, and the problems of high-temperature nuclear fuels for generating high-temperature process heat. These items for study are discussed in some detail in the body of the report.

(3) Nuclear batteries are small, expensive sources of energy useful for some remote applications. Their use in such ways appears to depend primarily upon identifying useful applications.

(4) Thermoelectric thermionic and magnetohydrodynamic methods of converting heat to electricity directly are in so undeveloped a state at the present time that a technical appraisal is not possible. While the performance of such devices can theoretically be good, such development depends upon the discovery of improved materials to establish practical feasibility. The needed research involves the development of materials having suitable electrical characteristics or resistance to ultrahigh temperatures.

(5) Radioisotopes are finding increasing use in gaging, inspection, and research, in this and other industrial countries. Further increases of isotope use for these applications appears to depend primarily on identifying suitable applications through the efforts of alert industrial and technical management familiar with the characteristics of isotopes. The amount of such application can best be stimulated in other countries by supplying information and training technicians in the handling and use of isotopes.

(6) Radiations as a promoter of chemical reactions are now economic in some cases. The research and development needs, for achieving more widespread usefulness, are in the field of finding chemical reactions especially suited for radiation activation, and in reducing radiation costs.

(7) Nuclear explosives need more investigation before useful applications can be identified and proved practical.

(8) The uses of radiation for food preservation require further evaluation before utility can be demonstrated. The research needed appears to be in the area of preventing undesirable flavor changes now produced by radiation, to prove the wholesomeness of irradiated products, and to assess economic factors.

(9) Many benefits have resulted from using atomic energy in agricultural research, and continued progress is expected in this area. Basic agricultural research done primarily in the well-developed countries of the world, and applied agricultural research done in all countries, should help increase the yield of the world's agricultural industry. Assistance to the underdeveloped countries, in the form of facilities,

training, information, and other forms of technical assistance, will enable them to make more rapid progress toward improving their agriculture through applied research and development.

(10) Medical research and diagnosis, as well as therapy, are of intimate importance to each individual of the world's population, and atomic energy has played an essential part in the medical science of the last 20 years. A still further expanded program of international cooperation in these subjects would be expected to provide greater benefits. Healthy and vigorous people are assets to the world's economy. Medical research with the aid of atomic energy can go far to maximize the quality of the earth's population.

INTRODUCTION

The choice of objectives for the United States international program in support of atomic energy involves considerations of many kinds – political, social, technical, and economic. The most basic of these are the technical and economic ones, for it is obvious that an atomic-energy application should be both technically feasible and economically attractive to merit even consideration in an international program.

In recognition of this fact by those charged with the review of the United States international atomic energy programs, the analysis which is reported in the following pages was requested. The intent of this analysis is to appraise the essential technical and economic background of each of many atomic-energy applications, and to estimate the usefulness of each application to other countries at various stages of their economic development. On the basis of the available information, conclusions about utility were reached, and these conclusions are given as unequivocally as present technology permits.

Two restrictions on these conclusions should be noted. First, no attempt has been made to draw comparative conclusions between alternative applications of atomic energy. The choice between supporting research on agriculture rather than on marine propulsion is not based primarily on technical or economic factors, but on political and social ones. Accordingly, an answer to this kind of a question is not attempted. Second, in discussing the potential benefits of various atomic-energy applications, abstract benefits are not considered. From a technical and economic standpoint, benefits are an improved standard of living and better health.

Actually, it is generally improper to discuss atomic-energy "Applications", for utility has not been demonstrated for most of the potential applications of atomic energy. In a few instances in every technical field, useful application of atomic energy has been

made but, for the most part, the potential of atomic energy is in the future, and has yet to be achieved through applied research and development.

As a consequence, the following discussions are largely concerned with the desirability of research and development activities, aimed at practical application of atomic energy, and with the usefulness of the application to other countries once it has been developed.

All proposed applications of atomic energy except central station power are treated in this report. These applications are:

(1) Research activities in all fields of science, on and with the aid of atomic energy

(2) The use of reactors for propulsion, process heat, saline-water purification, space heat, and for promoting chemical reactions

(3) The direct conversion of heat and radiation to electricity

(4) The industrial use of radiations and of radioisotopes

(5) The use of nuclear explosives for earth moving and for heat

(6) Radiation preservation of foods

(7) The use of radiations and tracers in agriculture

(8) The use of radiations and tracers in medicine.

A thorough evaluation of the potential usefulness of each application is impossible, even with the aid of the AEC staff reports prepared for the review and supporting reports and of the informed scientists who assisted in the preparation of this analysis. The reason is that some of the possible applications are so far in the future that their potential practicality cannot be judged. Only through much more research will it become possible to analyze the usefulness of such atomic energy applications.

A comment on the nature of the report may be helpful to the reader. The report has been written so as to be self-contained, to avoid the necessity for referring to many other reports for background. The salient facts for each of the subjects are discussed, with an analysis of the facts, as they apply to the United States international programs on atomic energy. The most important supporting information for each report section is noted.

Where appropriate, each section of the report covers the following aspects of its subject:

Technical state of the art, present and prospective
Research and development in progress
Nonnuclear means for achieving the same objectives
Present and prospective economic situation
Applicability to the economy of other countries
Means for encouraging useful atomic-energy applications.

The conclusions reached from this analysis have been summarized in the preceding section of this report and are given in more detail and discussed in the following sections.

BASIC RESEARCH IN ATOMIC ENERGY

It is through basic research* that potentially useful applications of atomic energy in many fields of science have been revealed. In a few cases, these applications are now in use, but in most, their ultimate value to the public has yet to be achieved through applied research and development. The types of applied research and development required before these applications of atomic energy can be put to practical use are discussed in the subsequent sections of this report.

In addition to such activities in applied science, there is a sizable basic research program which is being carried on in many scientific fields, either on or with the use of atomic energy. Research of this type is in progress in the fields of physics, chemistry, materials, biology, and medicine, as mentioned in the AEC staff reports(1)** on basic research and described in greater detail in testimony given before the Joint Congressional Committee on Atomic Energy(2). Such research will produce further scientific knowledge and more new ideas which will lead to other applications of nuclear energy, and to useful progress in other fields of science as well.

*The definitions to be used for basic research, applied research, and development are those which have been given in the National Science Foundation Reviews of Data on Research and Development for January, 1960. These definitions are as follows:

"Research is systematic, intensive study directed toward fuller knowledge of the subject studied. Research may be either basic or applied.

"Basic research is directed toward increase of knowledge; it is research where the primary aim of the investigator is a fuller knowledge or understanding of the subject under study rather than a practical application thereof.

"Applied research is directed toward practical applications of knowledge.

"Development is the systematic use of knowledge directed toward the design and production of useful prototypes, materials, devices, systems, methods, or processes. It does not include quality control or routine product testing."

These definitions will be used because they are fairly generally acceptable, not because the authors agree with them or believe that research can be so neatly categorized. A point of view more in accord with that of the authors has been expressed by J. R. Pierce, "Some Work on Hearing", American Scientist, 48 (1), 45 (March, 1960).

"---research must be judged by its quality and content, not by the initial motivation which led to the research. E. R. Steacie, President of Canada's National Research Council, has observed that if a laboratory connected with the railroad industry produced a new perfume, some who would be willing to call this "basic research" would refuse to describe as "basic research" anything useful in railroading. A consideration of motives is appropriate in the law. It can make the difference between hanging for murder or suffering a much lesser penalty for manslaughter. Such an examination is completely irrelevant and highly impertinent in judging the value of research. The quality of research must be judged by the quality of its content alone. The content will become neither better nor worse if we discover that the researcher undertook the work to improve or understand a system or device, to please a boss, to get away from his wife, to improve the lot of man, or to enjoy scientific discovery."

**References for this section appear on page 18.

Scientific activities of the above types – basic research, applied research, and development – are to be considered for support in the U. S. international programs on atomic energy. Applied research on a specific application might be supported because it is thought likely that such research would lead quickly to practical benefits. Basic research might be supported because it is believed that the resulting increased accumulation of fundamental data would, in the long run, produce even larger practical benefits. The decision of the type of activity which should be supported must be based to a considerable extent on the practical benefits which sooner or later are expected to result from such support.

In this discussion, we will confine our attention entirely to the practical benefits resulting from various types of scientific activity. Such an approach, applied to basic research for which the possible benefits cannot be predicted, may seem unjustifiable. Indeed, at one time it would have been, because not long ago all science was a cultural pursuit, like the fine arts. At that time, it was a spare-time activity of individuals, and the only motivation was intellectual curiosity. Then, science received only limited financial support, either from individuals or from universities where it was a justifiable expense because it contributed to the education of scientists. Under such conditions, curiosity about nature was adequate motivation for scientific research, and even today such motivation is still sufficient justification for research supported in that way, and for a certain amount of research supported by Government funds, as a cultural pursuit.

All research cannot now be justified in such a way because the status of science has changed so greatly in the present century, especially during the last two decades. Since science has been shown to have great practical value, it has become so big a business that in large part it must justify itself in terms of practical rather than intellectual values. A corollary to this is that today it is essential for both industry and government to invest heavily in scientific activities, if they are to compete successfully.

Thus, it is now entirely proper to discuss the usefulness of science, and indeed it is necessary to do so, for two reasons. First, scientific capabilities are an important national resource, and should be used as effectively as possible to promote the welfare and safety of a nation. Second, research has become a large-scale activity that derives its support primarily from public and industrial funds and, for that reason, is accountable to industry and government. For this reason the practical usefulness of science has become the major criterion used in deciding that science should be supported instead of some other governmental or industrial activity. Because of this fact, it is also necessary that serious study be given to learning how to make science as useful as possible, since in the present technological revolution, the one who progresses most rapidly towards the mastery of the techniques for effective use of science will win.

The problem of effective application of science is one of achieving a proper balance between science and industry, agriculture, and medicine, such that all parts are so organized they are able to contribute most easily and directly to the nation's welfare. There must be a complete technical and economic chain, linking the scientist and the factory worker and the farmer. All links of this chain must be strong, or the economy of the country will be neither as productive nor as progressive as it should be. What are the functions of each of these links in producing a strong economy?

Basic research has the ultimate goal of complete understanding of the physical universe. As progress is made towards this goal, new bits from the information being discovered are often found to have potential practical values, which can be achieved once they are put to use through applied research and development.

Traditionally, a great deal of basic research has been carried on in the universities, where it has been a part of the education of scientists, another important role

played by basic research.* Today, much basic research is also being done in government laboratories, industrial laboratories, and research institutes. Wherever done, the primary function of basic research supported with public or industrial funds is supplying new fundamental information, and disseminating it so that it may be put to practical use. It no longer is an end in itself.

Applied research and development are the links between basic research and the economy. Such scientific activities constitute the means for converting the output of basic science to a useful end product. Applied research has the additional purpose of developing new scientific information, when necessary for solving its problems. There needs to be good communication in both directions between applied science and basic research, since results in one of these fields can strongly influence progress in the other.

The final link in the chain is with the industry and agriculture of the country. Unless management is willing and able to accept the new products and processes, as well as the improvements in methods developed by science, and put them to use, the whole of the scientific effort would have no practical value. Management must be prepared to invest large sums of money to achieve the potential benefits from scientific effort.

It is evident that the effective use of science by industry and government depends on the quality and kind of both the scientific effort and the industry or government. All

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* Some concern has been expressed over too great expansion of research activities carried on in universities. J. H. Simons, "Scientific Research in the University", American Scientist, 48 (1), 86 (March, 1960), has said, "The Department of the Navy established the Office of Naval Research for the purpose of sponsoring and assisting academic scholars in departments of science in colleges and universities to engage in creative work of their own choosing and which they themselves desired to do."

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"This was a highly commendable effort on the part of the Navy and produced very beneficial results. Regretfully there have been very serious detrimental after-effects. The colleges and universities began to expect this financial assistance for meeting their own responsibilities in advancing human knowledge. In addition they expected the professors to seek and obtain such assistance in order to do creative work. A more serious harm has also resulted. A tendency has developed to favor members of the faculty willing and able to obtain such funds and provide fewer opportunities for those unable or unwilling. As these grants are made on the basis of a proposal which is evaluated by outside reviewers and approved or not by a Government bureau, highly speculative research is excluded from consideration. This type of work is the most important kind of research as it is the most productive of that which is new, and the university is about the only place where it can be done."

parts of the technical-industrial effort must be linked, for if any are not, the result is less than optimum. With this consideration in mind, let us next determine how various types of nations measure up to an ideal pattern.

In the United States, the relation between science and industry has been close, and our prosperity has in large part resulted from these close associations. Our ratio of basic research to applied research, however, may not be as high as it should, as some of our best scientists believe.(2) Furthermore, there may be some waste of scientific efforts, owing to duplication of research efforts in laboratories of competing companies, as some European scientists believe.* However, the Europeans miss a major point – it is largely because such competition does exist between our companies, forcing them into continual improvement, that American industry has progressed so rapidly and become so efficient. Such competition, between companies and between nations, is essential for most rapid progress, and may well be worth its cost in duplication.

The relation between science and industry is much different in Western Europe than in the United States. In large part this is because competition has in the past been stifled in Europe. With no incentive to achieve a competitive advantage, science was not applied as rapidly to the industry of those countries as it was in the U. S. This situation has recently been changing, with governmental encouragement of industrial research and enactment of antitrust legislation, and it is reasonable to expect that with such incentives science will in the future be used more effectively by European industry.

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* Bawn, C. E. H., "Some Impressions of Soviet Science", American Scientist, 48 (1), 50 (March, 1960).

"In the U. S. A. most of the research in polymer chemistry is carried out by the major chemical, oil, and rubber companies. The over-all effort is considerably greater than that in the U. S. S. R. but the quality of the Russian research was as good as any I saw in the U. S. A. and the approach, if anything, was more fundamental."

* * *

"The greatest contrast between the two countries, however, is in the organization and direction of research. The immense competition between the large chemical companies in the U. S. A. requires that each carries a very large research department which prosecutes very similar and often almost identical work. Any new idea or discovery immediately after its announcement is evaluated by innumerable companies, and the same fields of research are explored over and over again. The requirements of scientific manpower in this competitive business are enormous and one wonders if some other form for the effective utilization of limited numbers of highly trained scientists might be eventually devised."

Also, because of past European industrial practices, science and industry were not integrated so closely as in the United States, and as a result, applied science has, relatively, been neglected. On the other hand, basic research is being pursued vigorously in Europe, and has been for a longer time than it has here. In addition the proportion of European scientific effort being devoted to basic research is greater than it is in the United States. Because of the consequent underdevelopment of applied science, a longer time is normally required to make practical application of basic research information in Europe than in the United States. Furthermore, a great deal of European applied research is noncompetitive, and lacks the drive which makes U. S. applied research productive.

With these considerations in mind, let us consider the practical value of stimulating basic research as compared to applied research activities in Western Europe. In approaching this question, one encounters diverse opinions and prejudices. Some scientists believe that the European system of using science is the proper one, and such people are necessarily led to the belief that the U. S. basic research effort must therefore be inadequate. They conclude from this that basic research should be stimulated in the United States so as to be more in the European pattern, before such research should be supported abroad.

The contrary point of view is the one held by the authors. This is that the U. S. system of integrating science and industry is more productive and therefore that the welfare of Europe would best be served by stimulating applied research, and encouraging European management to use the output of science. This point of view should not be taken to indicate that the proportion of basic research done in the United States either is, or is not, adequate.

Neither of the above points of view leads to the conclusion that stimulation of basic research in Western Europe would provide them with increased practical benefits.

It would appear possible that this conclusion has been reached by those administering the United States Government international programs on atomic energy, for we do not support basic research on atomic energy abroad. We do supply the results of our own basic research, we help to train their scientists, and we have sometimes supplied tools for research. Such activities are justifiable on the grounds that, if a country is determined to support basic research, the best possible use should be made of the scientific thought being devoted to it.

For the underdeveloped countries, the situation is totally different. In this case, the following quotations from an article by Dr. G. B. Kistiakowski (3), convey our ideas better than we could express them.

"In helping to achieve a sound aid program, we, as scientists, must not think in terms of developing only the more advanced scientific capability of other nations, which is often a reflection of our own standards and comfortable abundance. We must try to strike a balance between basic needs and sophisticated development. This requires an appreciation of the way in which science and engineering develop within a nation. In many lands the history of science has not been written beyond the prologue. We must, for instance, be aware of the long-term relation between primary and secondary school education and advanced research institutions.

"We do little good by providing only for esoteric research facilities when a nation lacks roads, general practitioners, and machine operators."

He says, with reference to the conclusions stated in a report, "Recommendations for Strengthening Science and Technology in Selected Areas South of the Sahara":

"For a research scientist this report will have a sobering influence: it will point out to him that he is a luxury that can, and must, be afforded by an advanced nation like ours, whereas in Africa south of the Sahara, a nurse, an elementary school teacher, a technician – these are the luxuries."

Considerations of these kinds lead to the conclusion that the economic status of other countries would be benefited most through supporting applied rather than basic scientific activities. These are the type discussed in the subsequent sections of this report.

Such a conclusion pertains to the bulk of scientific activity. It does not apply to the outstanding scientist devoted to the conduct of basic research in his chosen field. It is in the best interests of the world's scientific progress to ensure that such people are somehow enabled to pursue their own course.

References

(1) USAEC Staff Reports on:

"International Cooperation in Basic Research in the Physical Sciences"

"Background Summary Paper on the Isotope, Radiation, and Research Programs of the U. S. as Applied to and Affecting Other Countries"

"Basic Research in the Physical Sciences"

(2) Joint Committee – "Hearings before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy Congress of the United States", Eighty-fifth Congress, Second Session on Physical Research Program as it Relates to the Field of Atomic Energy, February 3, 4, 5, 6, 7, 10, 11, 13, and 14, 1958.

(3) Kistiakowski, G. B., "Science and Foreign Affairs", Science, 131, p. 1019 (April 8, 1960).

APPLICATIONS OF NUCLEAR REACTORS AS HEAT SOURCES

The use of nuclear reactors for process heat, saline-water purification, space heat, and for propulsion is discussed in this section of the report. In such applications, as in the application of reactors to the production of central-station power, the nuclear fuel is simply a source of heat. Therefore, the sole criterion of the usefulness of reactors in such applications is whether they can compete economically with conventional sources of energy.

The conclusions reached for each of the applications is that nuclear reactors are not economically competitive at the present time, except under special and unusual circumstances. Thus, further reactor development is required before reactors can find wide use.

It seems obvious that such reactor development should be focused on that application for which reactors are best suited and which offers the possibility of most extensive use. Following such a course will make it possible to achieve the earliest and largest usage of nuclear reactors. In order to decide which application is best suited for reactors, let us compare the uses of reactors to be discussed later in this section with their use for the generation of central-station power.

Reactors are not economically competitive at the present time, because both capital cost and fuel cycle costs are high. Capital costs will always be relatively high for nuclear reactors, because radiation hazards must be rigidly controlled. This disadvantage is least limiting for large plants and for those having a high load factor.

Fuel costs are also high at the present time, although the fuel itself is intrinsically cheap per unit of heat produced. Important fuel-cost reductions appear achievable through research and development, and ultimately through large-scale processing of nuclear fuel of only a few types. The needed development will proceed most rapidly if it is concentrated in the medium- or low-temperature range.

With these considerations in mind, let us examine each of the reactor applications later discussed, and determine whether any of them might be a better choice than central-station power applications, as the focus of reactor development.

(1) Applications of heat energy in manufacturing industries now consume 25 per cent of the fossil fuel used in this country. About 10 per cent of this, or 2 to 3 per cent of the total, is used for the production of electricity within the industrial plant. Of the balance, a large fraction is used by industries which use by-product fuel or require high temperatures, and are not now replaceable by nuclear fuel. Thus, the over-all potential markets for nuclear process heat at low or medium temperature are not nearly as important as electricity production, which uses 19 to 20 per cent of our fossil fuel, all of which potentially can be replaced by nuclear fuel, when the latter becomes economic.

Other factors which tend to cause process-heat applications to be less attractive than electric-power production are that process-heat units are generally small, are apt to have a low load factor, and may be used in industries where rapid amortization is necessary to combat obsolescence.

(2) Little needs to be said of space heating, which is particularly unsuited to nuclear power because of the very low load factor. Central-station space heating is relatively uncommon even with fossil fuel, and the small units otherwise needed are much too small for reactors.

(3) Saline-water purification is technically suitable for reactor applications, but is not yet a proper subject for extensive reactor development because there are pressing problems which must be solved in technical

areas other than reactor development, before economic application is possible.

(4) Marine propulsion offers only a small market for nuclear reactors, so the application does not merit being made the focus of any larger reactor development program than at present.

Because of these considerations, the conclusion is reached that central-station power applications should continue to receive the bulk of the United States reactor-development effort. This application has the characteristics best suited to nuclear reactors – large units, good load factor, and large fuel requirements – and is most likely to be the first reactor application which is both economic and a large-scale use. The same conclusion applies to reactor programs supported in the United States international programs.

It is also worth noting that, when central-station power use of reactors has been developed to the point where it is economic, the technology can be used directly for the engineering of low- and medium-temperature process heat, for saline-water purification reactors, and, to a considerable extent, to reactors for marine propulsion.

These considerations do not apply to the cases where the unique characteristics of reactors help them to perform unusual tasks. Reactors may be unique either because they are intense radiation sources and find use as research reactors, medical reactors, chemonuclear or food irradiation reactors, and in the direct generation of electricity from fission recoils, or because they are self-contained power sources and find use in submarine propulsion and in remote power sources.

When used for such purposes, the performance characteristics of reactors often transcends economic factors, and the merits of each application must be considered as an individual case. Several of these unique applications are discussed in other parts of this report.

Low-Temperature Process Heat

The AEC has defined the low-temperature process-heat region as that where the temperatures encountered are less than those normally existing in reactors designed for electrical power generation. The temperature range might be defined as that below 380 F. In this temperature range, several reactor types, notably the pressurized water (PWR), boiling water (BWR), and organic moderated (OMR) types, have well-developed technology and technical feasibility is well established. Accordingly, the potential and the prospects for nuclear energy in this application are directly related to the comparative cost of heat from fossil fuel under the same conditions (e.g., plant location, accounting methods, plant duty cycle, etc.). In addition, the potential market for process-heat plants which might be supplied by nuclear plants, if economical, must be examined.

Status of the Economics of Nuclear Reactors for Process Heat

During the last several years the design studies and economic analyses which have been under way at Argonne National Laboratory and the AEC headquarters have been directed toward the application of nuclear reactors for low-temperature process-heat production. Some of the results of these studies are reported in References 1 and 2.* As might be expected, the economic comparisons with fossil fuel plants are complex and highly dependent upon the assumptions used. However it is instructive to examine the results given in Table 1 for one case studied[1] where nuclear fuel was shown to be competitive with fossil fuel. This table gives data on a comparison of 40 Mw (t) plants producing saturated steam at 380 F by a modern coal plant and a PWR-type reactor plant featuring carbon steel in the primary pressure system and

*References for this section appear on page 45.

TABLE 1. 40 MW (t) PLANTS PRODUCING SATURATED STEAM AT 380 F

Cost Items	Conventional Coal-Fired Process Heat, cents/1000 lb steam	Nuclear, cents/1000 lb steam
Capital charges	21.2	39.8
Fuel	60.0	21.0
Operating costs	8.3	15.8
Fuel inventory	1.0	11.0
Total Costs[a]	90.5	87.6

Assumptions[b]

14 Per cent capital charges	Nuclear fuel:	
80 Per cent load factor	Average burn-up	12,700 Mwd/MT
Coal cost, 45 cents per million Btu	Fabrication cost	$85/kg
Coal inventory, 2-month supply		

(a) Does not include insurance.
(b) Other assumptions taken from ANL-6009.[2]

aluminum-clad UO_2 fuel elements. The following points are significant in this comparison.

(1) A coal cost of 45 cents per million Btu was used. This cost corresponds to about the highest coal cost in the United States. Since the fuel cost is the largest factor in the conventional plant total cost, the nuclear plant would not be competitive in any other location. With coal costs of 35 cents per million Btu, the total cost would be 77 cents per 1000 lb of steam for the coal-fired plant.

(2) 14 per cent capital charges were used. Depending upon the particular accounting practice in the industry installing the plant, the capital charge might be as low as about 6 per cent or as high as about 30 per cent. Since the nuclear plant is about twice as expensive in capital cost as the coal-fired plant, the capital charge rate would make a drastic difference in the competitive position of the two plant types.

(3) The assumptions of average fuel burn-up and fabrication cost are based upon present technology. They are believed to be conservative. However even if they could be improved by a factor of 2, the effect on total cost for the nuclear plant would be only about 10 per cent.

(4) The 80 per cent load factor assumption tends to favor the nuclear plant. A reduced load factor would affect the nuclear plant in capital charges, fuel inventory, and to some extent in operating costs. Each of these items is significantly higher in cost than the conventional plant under the present favorable assumptions.

These considerations suggest that at the present time there is no economic advantage of nuclear energy over fossil fuel in this application. Furthermore, in order for a significant economic advantage to exist in the future, either

(a) Fossil-fuel cost will have to increase markedly, or

(b) Nuclear process heat plants will have to be designed in such a way that the capital cost is more nearly comparable with the capital cost of a conventional plant.

Potential Markets for Nuclear-Generated Low-Temperature Process Heat

The principal applications of low-temperature process heat involve the use of saturated steam to furnish heat for manufacturing operations such as drying, evaporating and condensing, distilling, and food processing. The usual steam conditions are in the range of temperatures up to about 400 F or 250 psig, but more generally in the range of 50 to 150 psig.

Of the total primary heat energy consumed annually in the United States during recent years, about 25 per cent was used by the manufacturing industries.[3,4] In 1958, this represented the use of about 10×10^{15} Btu. Of this amount, about 10 per cent was used for the generation of electric power at the plant site. The remaining 90 per cent represents heat energy used for nonpower purposes, of which about one-third was used in direct firing (high-temperature process heat) and two-thirds to raise steam for process heating and some space heating.[4] Also to be added to the latter classification is a substantial part of the heat value of the steam generated by industry for power production, which is subsequently extracted from the turbines for use as process steam.

Table 2 shows the consumption of heat energy in the major categories of manufacturing industries for nonpower purposes in 1954, the latest date for which complete Bureau of Census figures are available. Also shown are estimates[4] for 1967, which indicate a substantial increase during the 13-year period, the largest increases being in the petroleum products and metals categories.

Several studies[4,5,6] were made during 1957 and 1958 which, by detailed examination of data compiled by the Bureau of Census, boiler manufacturers, and industry

associations have broadly outlined the potential markets for nuclear-generated low-temperature process heat. These studies have shown the pattern of boiler installations made in the manufacturing industries over a period of the past 10 or 15 years with respect to capacities of individual boiler units, steam conditions, plant location, and fuel costs.

By a process of elimination, a number of the largest industrial users of process-heat energy can be removed from the list of manufacturing industries offering a significant potential market for nuclear process heat. Either because process heat is required in the high-temperature range for direct-firing applications, or because of heavy use of plant-generated waste or by-product fuels, or both, the industries listed as Group 1 in Table 2 can be said to offer low potentials for the use of a competing fuel. This group comprises almost 67 per cent of the heat consumed by manufacturing industries. As compared to Group 2, this group is characterized by (a) a relatively lower proportion of the total capacity of boiler additions in relation to its total heat consumption, and (b) fewer but larger installations.

The manufacturing categories listed under Group 2 in Table 2 offer a larger potential for nuclear-derived low-temperature process heat because (a) the steam boiler capacity is large in relation to its heat consumption (31.5 per cent of total heat consumption vs. almost 60 per cent of total boiler capacity additions), (b) lower use of direct fired heat as compared with Group 1, and (c) low availability of by-product fuels, except for pulp and lumber mills.

Although the results of the limited number of studies made to date have shown that a potential market for nuclear-derived steam heat does exist, generalizations may be quite misleading. The complex relationships of other technical and economic factors involved in attempts to determine the most favorable potential installations require that more detailed market studies be made. Included among these factors are (a) size of

TABLE 2. CONSUMPTION OF HEAT IN MANUFACTURING INDUSTRIES FOR NONPOWER PURPOSES[3]

	1954		1967
	Btu x 10^{12}	%	Btu x 10^{12}
Group 1. Uses Offering Low Potential For Nuclear Powe.			
Primary metal industries	2,666	30.6	4,678
Products of petroleum and coal	1,843	21.2	3,522
Stone, clay, and glass products	840	9.6	1,256
Machinery (including electrical)	314	3.6	531
Fabricated metal products	152	1.7	324
Instruments	20	0.2	28
Subtotal	5,835	66.9	10,339
Group 2. Uses Offering Significant Potential For Nuclear Power			
Chemicals and allied products	959	11.0	1,614
Food and kindred products	689	7.9	907
Paper and allied products	494	5.7	656
Transportation equipment	206	2.4	324
Textile mill products	196	2.3	227
Lumber and wood products	97	1.1	140
Rubber products	69	0.8	81
Leather and leather products	26	0.3	29
Subtotal	2,736	31.5	3,978
Group 3. All Others			
	141	1.6	236
Total, all manufacturing	8,712	100.0	14,553

Source: Prehn and Tarrice, Reference 4.

unit installation, (b) load factors, (c) capital cost vs. payback time, (d) plant location vs. competitive fuel costs, (e) the plant demand for electric power and process heat, and (f) the percentage of total product cost represented by process heat.

Plant capacity is a factor of importance. Manufacturing industries are characterized by the use of many small units. Of the total number of boilers installed by manufacturers between 1945 and 1957, more than half had steam capacities of less than 40,000 lb per hr (<12 Mw thermal), and almost 85 per cent had capacities under 100,000 lb per hr (<33 Mw thermal).[5] On the basis of present technology and economics, the high capital costs for small reactor units would severely limit their application.

The higher capital costs of nuclear steam plants is a distinct disadvantage in manufacturing industries accustomed to short payback periods for major items of equipment; the chemical industry is an example. Unlike electric utilities, which can use long-term methods of financing, a rate of return of perhaps 30 per cent on invested capital is usually required. Such industries have a lower ratio of fixed assets to total assets than do electric utilities. Industries in which fuel costs represent a relatively small proportion of the value of the finished product are less concerned about either fuel price or fuel efficiency but are greatly concerned with receiving a rapid payback on capital invested in equipment.

Low load factors averaging from 10 to 30 per cent are characteristic of industries such as foods and textiles. The high capital costs of nuclear reactors would be a heavy economic disadvantage in these industries.

The competitive aspects of fossil fuel with respect to potential locations for nuclear process heat reactors are more obvious. Even here, however, generalizations can be misleading, and an analysis of potential applications can be made for specific locations only after the effects of all other factors have also been evaluated.

The conclusion of market studies that have been made indicate that the manufacturing categories of chemicals and allied products and paper and allied products should

offer the largest potential for use of nuclear-generated low-temperature process heat. This general conclusion was also reached during discussion at the Symposium on Low-Temperature Nuclear Process Heat sponsored by the Atomic Energy Commission in October, 1959.[7] Specific applications, however, can be determined only by more detailed market research. In general, the higher capital costs of nuclear-derived heat will present a much greater handicap for nuclear applications in the process-heat field than in the utility field, where it already is a major factor.

Conclusions and Recommendations

It can be concluded from studies made to date that estimated costs of reactor-generated steam might be marginal at present for only a few of the manufacturing industries and only for locations in areas of high fossil-fuel costs. Within these, specific plants can be pinpointed only through more detailed economic studies. As reactor costs are reduced, particularly capital and associated costs, there may be a gradually increasing number of instances where reactor-generated steam would cost no more than that from conventional fossil-fuel-fired plants. The present AEC program specifically concerned with low-temperature nuclear process heat appears to be adequate in view of the market potential in this area.

On the technical side, all of the approaches to a reactor for low-pressure steam generation have been modifications of reactor concepts found promising for electric-power generation. The less severe operating conditions have suggested the substitution of less expensive construction materials in the low-pressure reactor, with the possibility of lowered capital costs. There seems little incentive to do otherwise in the future, so that technical developments in this area will generally follow developments in power-generating reactors.

In other countries the situation should not be much different. In those not highly developed industrially, there will be small potential for process steam in the medium

and higher capacity ranges which will be first to reach competitive status; in the more highly developed countries with an advanced industrial complex, the progress in nuclear-power generation probably will more nearly keep pace with ours. This then should lead to modifications specifically aimed at low-cost production of process steam. Beyond publication and exchange of information, there seems little that should be done specifically to foster development in this area.

Desalinization of Water

This application is much better suited to the characteristics of nuclear reactors than are other applications for low-temperature process heat. The reasons for this are (a) very large units are suitable, for which the capital costs of reactors relative to fossil-fuel-fired boilers are at a lesser disadvantage than those for small units, and (b) the plant load factor would be high, also helping to reduce the fixed charges.

The situation and prospects for desalinization by atomic energy are discussed in adequate detail in the AEC status report on industrial applications of reactors.(8) As stated there, the success of either reactors or conventional fuels in this application depends to a considerable degree upon the development of an economical evaporator that will allow potable water to be produced at a reasonable cost. The following information has been taken from the AEC status report.

> "The AEC has investigated the use of a nuclear reactor specifically designed for the production of low temperature and pressure steam which can be used for the evaporation of sea water. It is concluded that while this application is interesting and shows promise in the long range future, the success of such an application depends largely upon developing an economical evaporator. The development of such an evaporator is clearly within the functions and responsibilities of the Office of Saline Water of the Department of Interior. At this time, the Office of Saline Water is

necessarily vague in their estimates of the potential use or need for such a reactor. This vagueness is due to the uncertainty in their predicted future costs and in the expected results of their current demonstration program.

"The Office of Saline Water's demonstration program provides for the construction and operation of five one-million gallon per day water plants to determine the engineering feasibility and economics of large scale water production. The AEC is cooperating with them on one of these plants by the construction of its Experimental Low-temperature Process Heat Reactor authorized for FY 1960 at the site of the Office of Saline Water's West Coast Sea Water Distillation Plant at Point Loma, San Diego, California.

..."The construction and operation of the Experimental Low-temperature Process Heat Reactor will provide an experimental facility specifically designed for the production of process heat. Additional basic supporting research on this reactor application will be necessary and will undoubtedly be done at one of the AEC's national laboratories. The amount of research is expected to be quite small because of the wealth of information already available from the Commission's power reactor program."

Conclusions and Recommendations

Saline-water purification is the application of low-temperature process heat best suited technically to the characteristics of nuclear power. Construction and operation of the ELPHR will provide data useful for assessing the economic potential of nuclear power for saline water purification. Factors relating to the economic suitability of this application, on which further study would be helpful, include:

(1) Methods for reducing fuel cycle cost, by intensive development of processing and reprocessing for the most appropriate fuel

(2) Detailed analysis of the opportunity for reducing capital cost, partly by choosing remote applications which often will be suitable

(3) Study of the problems of efficient evaporators.

Such an application of atomic energy might find use in many parts of the world, if the economic situation were such that the water-poor country could afford to pay the costs for water. Only a detailed economic analysis, made after further experimental studies, would permit definite conclusions to be drawn about the extent of use.

Intermediate-Temperature Process Heat

The AEC has not placed any special emphasis on developing process-heat reactors for this temperature range. Reactors for application in this temperature range are identical with those for supplying heat for the generation of electricity. The mere application of these reactors to producing the same type of heat for the processing industry is not a research or development problem, and the process industries will be able to adopt them as soon as they become economically competitive.

The course of the AEC seems sound, and it appears that the same conclusions apply to the international atomic-energy programs.

High-Temperature Process Heat

By definition, nuclear reactors to produce high-temperature process heat require fuel elements to operate well above 2000 F. This temperature requirement exceeds the present state of the art for producing practical fuel elements for this application. The problem of suitable high temperature fuel elements is an important and difficult one, and it now appears that much research will be needed to further increase the allowable operating temperature for nuclear fuels. Such advances of technology will enable nuclear reactors to perform tasks now beyond their capabilities, so it is important that studies of high-temperature fuel materials be pursued vigorously.

Space Heating

An AEC status report[8] contains an evaluation of the use of reactors for space heating, with which we concur. This statement is as follows:

> "Studies concerned with the economic feasibility of building reactors for space heat, both from the military and civilian viewpoint, have been made by the AEC. While the studies of military applications have shown nuclear reactors to offer some promise in remote areas, these areas also require power. Thus, they require the use of an intermediate-temperature range reactor in which the higher temperature heat is used for producing electricity and the heat rejected by the power turbine is used for space heating. Investigations for use in civilian applications have shown reactors to be uneconomical because of the small size of the installed unit and load factors. The load factor of space heat boilers varies between 20 and 25 per cent, making it difficult to justify the higher capital cost of a nuclear installation. In view of the lack of economic promise for such applications, the AEC has no immediate plans for specific work in the field of civilian space heating. Data from the military reactor program relating to such application is available, however."

The waste heat from reactors has been used for space heating. The first application of this type was at Harwell. Such applications will always be minor, and do not merit consideration in this report.

Merchant-Ship Propulsion

General Status

The application of nuclear energy to merchant-ship propulsion is receiving considerable attention from the leading maritime nations of the world. The AEC status

report to the McKinney Panel[9] provides a thorough summary of the status of the ship-propulsion programs in the various countries. Briefly, in Japan, United Kingdom, Norway, France, Italy, the Netherlands and Sweden, the programs are in the study and planning stage and no actual nuclear ship building is yet under way. However, the initiation of construction programs appears likely within the next several years. In West Germany a grant of approximately $4 million for the construction of an organic-moderated reactor to be installed in a tanker, the ESSO Bolivar (15,256 dead weight tons) in December, 1960, has been announced.

The United States has the most advanced program of all: the construction of the NSS Savannah is scheduled for completion in late 1960. In addition, the development of an advanced system, a gas-cooled reactor plant, is in progress.

Some factors of the technical feasibility of nuclear power for marine propulsion have been established by the success of the United States nuclear submarines, and the U. S. S. R. icebreaker Lenin. These applications have shown that when power cost is not the primary consideration, reactors can be designed to fit into ships of conventional size, built, operated, and maintained, without undue radiological hazards, and with high reliability.

However, reactors of this type have not been optimized for merchant-ship propulsion, and would not be economically competitive with conventional power. To achieve economic competitiveness in such applications, other reactor designs will be needed using less highly enriched uranium and cheaper materials and methods of construction. To some degree, such basic changes of reactor design will reopen the question of technical feasibility, for some of the changes made to lower costs could affect the hazards of reactor operation, or problems of maintenance and reliability.

One very important aspect of the application of nuclear energy to marine propulsion which warrants considerable attention is the effects of radiological hazards

from ship damage. Since annually between 2 and 3 per cent of all merchant ships over 500 tons are damaged by fire or collision[10], insurance rates for nuclear-powered ships could be expected to be quite sensitive to any increased liability from radiological hazards.

The Economics of Nuclear Merchant Ships

United States. A comprehensive study of this subject from the standpoint of the U. S. Merchant Marine has been conducted by the American Radiation and Standard Sanitary Corporation for the USAEC.[11] Nuclear and conventionally powered ocean-going merchant ships were compared in the period 1957-1970 using cost per unit carried and return on investment as the basis for comparison. To perform the comparisons, capital and operating costs were determined for these ships operating at various trade route distances and speeds. Ship types used were based on existing or proposed ships with known characteristics. Four reactor types were used in the analysis: pressurized-water, boiling water, organic-moderated, and closed-cycle gas-cooled.

Within the framework of the assumption that all nuclear plants are fully developed and operational, it was concluded in this study that the organic-moderated and boiling-water systems offer the earliest opportunity for achieving a competitive position with fossil-fuel plants. Ore carriers have the greatest economic potential for nuclear propulsion. Tankers and general-cargo ships, in that order, are the next best types for consideration of nuclear propulsion, with passenger and passenger-cargo ships having the least potential. Nuclear ships gain a better competitive position as compared with conventionally powered ships at long trade route distances and high speeds.

The conclusions and recommendations from this study are given at the end of this section, on page 46. They appear to be consistent with the information developed in the study.

Other Countries. Published reports[12,13,14,15] of studies of the economics of nuclear merchant ships have been made by British, German, Norwegian, and Japanese authors. Although differing in some details, their findings are in general agreement with those of the United States study. A somewhat different approach from the others was taken by the Japanese in considering a ship to carry Japanese emigrants to South America.[14] In this case, a nuclear-powered vessel was designed to best utilize this source of power. Economic comparison was made with a smaller conventional ship presumably optimized for its power plant. Voyages, size, and speed were thus chosen in each case to optimize costs for the particular power plant.

On this basis, the nuclear-powered vessel gave a 20-year average rate of profit on capital of 17 per cent per year, compared with 34 per cent for the conventional ship. However, the authors concluded that both types of vessel are economically profitable.

Evaluation of Available Information

Economic. With the exception of the Japanese emigrant ship study discussed above, all of the economic studies reviewed performed economic comparison by substituting a nuclear plant for a conventional plant in the same ship hull plying the same trade routes. Under these conditions the variable parameters are essentially speed and size. The primary recognition of the differences in the power plants is fuel weight, fuel inventory cost, insurance rates, and labor.

When this type of comparison is made, the gross results appear to be as follows:

(1) Fixed costs per day make up 80 to 90 per cent of the total cost of operation.[11] Thus, fuel cost, which is the major variable daily cost, is not the dominant cost item in merchant-ship operation.

(2) The largest single item in the fixed costs of conventional ships is amortization charges, which run approximately 45 to 60 per cent of

the total daily fixed costs (of all but passenger and passenger-cargo ships).[11] In nuclear-powered ships the capital costs, and hence amortization charges, run about 30 to 40 per cent greater than conventional power.[11]

(3) Significant but less important items in the daily fixed cost are:[11]

Wages which are 15 per cent of daily costs for tankers, general cargo ships and ore carriers, and 30 to 35 per cent for passenger-cargo and passenger ships, are 7 to 10 per cent greater on nuclear ships.

Insurance, 13 per cent; 60 to 100 per cent greater than conventional ships.[11]

Nuclear fuel inventory, 3 to 8 per cent.[11]

(4) Variable daily costs include fuel costs as the largest item.[11] Comparisons indicate that nuclear fuel costs are about equal to or somewhat less than conventional fuel costs, depending upon the assumptions used in arriving at the nuclear fuel costs.

With this type of cost structure, it is almost inevitable that nuclear power will be best under conditions which yield the maximum number of ton-miles per day. These conditions seem to be:

(1) Large, fast ships (The capital cost of reactors goes up less rapidly than their size. Thus, increasing the reactor size by a factor of 5, increases its cost by only about 2.5 times.).

(2) Long voyages (to increase the duty cycle).

(3) Bulk cargoes (to minimize time in port, which also increases the duty cycle. Also, conventional fuel in this case takes up cargo space.).

Owing to the dominance of amortization charges in the cost structure, comparisons between reactor types will favor the plant with the lowest capital cost. Of the types generally considered, this effect tends to favor the organic-moderated over the boiling- or pressurized-water and gas-cooled reactor types, because of the lower cost of the primary system components.(11)

Hazards and Insurance Rates. The hazards of operating a nuclear-powered merchant fleet either from the standpoint of its effect on safety to lives and property or from the standpoint of its effect on the increased cost of liability insurance(10) are greater than for land-based plants. Much attention has been given to reducing the risks of serious reactor accidents of land-based reactor plants to an acceptable level. This has been achieved through careful design of safety features, reactor containment, and remote location. The designers of ship reactors face a far more difficult problem. Their reactors will not be in remote locations, and there are hazards not present in land-based reactors.

For example, a ship reactor faces many accident risks from causes incident to the ship's operation, including vibration, heavy-weather motion, fire, cargo explosion, collision, flooding, capsizing, or grounding. Over the past years, between 2 and 3 per cent of vessels over 500 tons have been damaged in collision and fires each year. It is logical to conclude that serious accidents involving nuclear vessels are inevitable. These factors suggest two aspects that are unique and vital to the acceptance of nuclear power in the merchant marine of the world:

(1) The probability of damage to nuclear power plants from causes external to the reactor system is high. Accordingly, the reactor design must minimize the consequences of such damage. Since this requirement will be reflected in the capital cost of the ship and its plant, it may dominate the choice of reactor types.

(2) The liability insurance rates that might be applied to nuclear-powered ships need to be very carefully derived in estimating the comparative economics.

The reason for the concern over this point is as follows. The American Standard Study reported that in 1957 the insurance rates for conventionally powered ships were estimated to be about 10 per cent of the daily fixed costs.[11] Comparative rates for nuclear-powered ships were estimated as 60 to 100 per cent greater. However, the basis for the increased premiums for the nuclear-powered ships was (a) the increased capital cost and (b) the liability premium established by The Nuclear Energy Liability Insurance Association as the highest rates for land-based central-station nuclear power plants. Owing to the high probability of damage and the consequences thereof in marine installations compared with land-based nuclear plants, it is questionable whether these liability rates are applicable. Since insurance premiums are roughly proportional to the product of the probability of an accident during the premium period and the liability incurred in such an accident it appears conceivable that the marine rates might be considerably higher than such estimates. If so, they may dominate the economics of nuclear-powered ships.

Research and Development Needs. In many ways the problems of developing reactor power plants for marine application are similar to those for land-based central-station power plants. Hence, much of the basic technology is identical and advancements in technology for land-based plants can be utilized in marine applications. Both applications are influenced by the same economic needs to reduce capital plant costs as well as fuel cycle costs.

Marine reactor installations differ from land-based plants in size, reactor power level, weight, layout, operating schedule, and hazards. These requirements lead to cores of higher enrichment and to somewhat different control requirements. However,

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these factors are in the realm of engineering design criteria rather than differences in basic technology.

The areas of research and development needs that are unique to marine application, where available information appears inadequate, are as follows:

(1) A comprehensive analysis of the risks and consequent liability of nuclear-powered merchant ships leading toward realistic estimates of insurance rates. It should be noted that hazards will vary for different reactor types, and need to be considered in this analysis. It is not adequate to consider that the hazards of various reactor types are the same.

(2) The analysis of reactor plant layout, shielding, and shipboard location to optimize total operating economics. This subject could indicate the need for experimental studies which might include:

(a) Shielding studies of materials which could best serve a dual role of shielding and minimizing the effect of external damage.

(b) Studies to determine and find ways to minimize the effect of externally caused damage to the reactor core.

(c) Studies to provide sound estimates of the release of radioactivity under conditions of serious ship damage and/or sinking.

(d) Studies of the effect of reactor type (boiling water, pressurized water, organic cooled, etc.) on safety during accidents or shipping.

(e) Studies of the effect of reactor type on accessibility for maintenance.

(3) Studies of present ship types which best utilize nuclear power plants. Studies of this kind might be expected to lead the way toward considerable cost reduction for nuclear ships in the near future. On this subject the American Standard study reports[11] "Since the size and cost of the reactor plant increases slowly as compared to the power output required, sea speeds in excess of those presently specified may be economically desirable. Very large, full, and very fast ships may be designed to have maximum stability and still be more economic.... To maintain high sea speeds, sea-keeping characteristics must be maximized, permitting full utilization of the installed plant. In addition, cargo discharge and loading must be accelerated to warrant the high ship speeds."

(4) Studies of advanced nuclear ship systems which fully utilize the capability of nuclear power.

It is apparent from the published reports here and abroad that much of the thinking and study of nuclear ships has been based upon the simple substitution of a nuclear plant for an oil-fired plant in a more or less conventional hull. Economic comparisons are then made on the basis of this substitution using trade routes, ship sizes, speed ranges, in-port time, etc., of well-established marine practice. However, all of this established practice is based upon the optimization through many years of experience of a merchant marine industry using oil-fired power plants. In Battelle's opinion, it is just as incorrect to assume that this is the best way to utilize nuclear power as it would be to make similar comparisons of oil-fired plants in sailing vessels.

Accordingly, there seems to be a need for more-than-casual studies of advanced ship systems from this standpoint. The future development of such advanced systems would, of course, depend upon the study results.

As a purely illustrative example of the type of thinking this approach might entail, consider a sea-train concept, either surface or submarine. The nuclear-powered "locomotive unit" stays at sea almost continuously, towing "trains" between ports (but not into harbors). This type of operation increases the duty cycle and minimizes liability insurance premiums. Furthermore, under these conditions the optimization of cost per ton-mile might well turn out to be relatively independent of length of trade route, speed, and size of vessels in the train. If this were the case, the range of economical operation of nuclear power might be increased.

The economy of nuclear-powered ships may be greatly dependent upon totally new concepts developed in other technologies. As a possibility of this type, it might be noted that some recent developments by the U. S. Rubber Company suggest that it may ultimately be possible to greatly reduce the drag of submerged vessels, though not of surface vessels. Such a development might greatly improve the potential for a cargo-carrying submarine, which would almost certainly depend upon nuclear power for propulsion.

Future Prospects and Areas for International Cooperation

The general consensus of published reports on the prospects for economic operation of nuclear ships is that they are definitely encouraging. Owing to the large uncertainties in the estimate of the cost factors, the prospects of economic operation within the next 10 years, however, depend upon the optimism of those doing the analyses. Whether based on realism or national pride, it is a fact that the idea of nuclear-powered merchant ships has aroused the interest of the maritime nations of the world. It is also obvious that the United States has done more than any other nation in conducting programs that will contribute significantly to evaluating the prospects for a nuclearized merchant marine.

On technical and economic grounds it appears that our present development efforts will continue to supply the data needed for an ultimate evaluation of this application of atomic energy. As was discussed above, the considerable effort in achieving economic central-station power in this country is largely applicable to economic nuclear ship operation. The considerable knowledge gained through the naval ship program is certainly applicable to the merchant marine. Thus communication of this country's integrated experience to other countries could help immeasurably in their efforts to apply nuclear power to their merchant marines.

In addition, advanced studies along the lines proposed earlier in this report appear desirable. These studies, it will be recalled, include: evaluation of ways in which present concepts of ship design might be modified to take better advantage of the special characteristics of nuclear power; study of maintenance problems; and a thorough analysis of the hazards of marine nuclear propulsion including the effect of reactor type, to enable a realistic insurance rate to be determined.

For the reactor itself, the problems are for the most part very like the problems of central station power application, and the same research programs will help towards their solution for marine propulsion applications.

At some time in the future, assuming that economic ways of utilizing nuclear energy for merchant-ship propulsion are found, and that large-scale application is undertaken, there will be a need for a number of nuclear fueling stations at strategic points. Such stations might have the following characteristics:

(1) They would be located in a sparsely populated area to reduce the effects of nuclear hazards.

(2) They would provide all of the facilities for loading and unloading cores, repairs to reactor systems, inspection of the primary coolant system,

etc., in addition to the normal ship-maintenance facilities. These various facilities might well include:

(a) Hot cells for inspection of spent fuel

(b) Means for transferring spent fuel elements to shipping casks

(c) Means for checking criticality conditions of new cores prior to power operation

(d) They would provide a staff of trained technologists to perform the necessary functions in a safe and efficient manner.

Construction of refueling stations of this type might be considered by the United States at some time in the future.

Such an establishment, made available at an appropriate time, might do much to encourage other less developed countries to obtain and operate nuclear-powered merchant vessels.

Railway Propulsion

Battelle concurs in the conclusion of the AEC status report that the safety problems of a nuclear-powered locomotive are formidable. The prospects for the use of nuclear energy in this application are very poor. A discussion of this subject is given in Volume 2 of the 1956 report on the peaceful uses of atomic energy.

Aircraft and Space-Vehicle Propulsion

The overwhelming motivation for developing nuclear energy for these applications is military rather than civilian. Although indirect benefits from the present research and development programs for these applications may accrue to the civilian peacetime

applications, no direct research and development effort from this standpoint is warranted, and no potential is seen for civilian nuclear-powered airplanes, or for rocket propulsion for uses of international application.

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From the results of this project, several important conclusions can be drawn:

(a) Nuclear ships can economically compete now with conventional ships on long trade routes at high speeds.

(b) The competitive position of nuclear ships will improve in 1965 and 1970.

(c) Nuclear fuel costs are, in most instances, lower than conventional fuel costs.

(d) Nuclear ship capital costs are 10 to 50 per cent higher than capital costs for conventional ships (except for gas-cooled reactor-powered ships).

(e) Capital costs for nuclear ships will decrease with respect to capital costs for conventional ships in 1965 and 1970.

(f) Ore carriers and tankers have the best potential for the economic application of nuclear power to merchant ship propulsion.

(g) Nuclear power is particularly attractive in trades that require small ships on long trade routes.

Generally speaking, nuclear ships will become more competitive at an earlier date on the basis of cost per ton than they will on the basis of return on investment. This is because nuclear ships have relatively low variable operating costs but have higher capital and fixed costs than conventionally powered ships. Therefore, the attractiveness of nuclear ships to ship operators will depend to a great extent upon the time value of money and the method of financing the construction cost of the ships.

Within the framework of current maritime practice, ore carriers have the greatest area of economic potential for nuclear propulsion. Valuable cargo tonnage in nuclear ships of this type is not sacrificed for fuel space. In addition, this type of ship is usually large and requires a large amount of power, which nuclear plants can provide at a relatively low fuel cost.

Ore carriers powered with organic-moderated or boiling-water reactors in 1957 can move cargo on 16,000 to 20,000-mile round-trip routes at 19 to 22 knots at the same unit cargo cost as conventionally powered ships. By 1965, large nuclear ore carriers operating at 21 to 22 knots on long trade routes will be able to carry cargo at about

nine-tenths the unit cargo cost incurred by counterpart conventional ships at the same speed. Moreover, these large nuclear ships will be competitive on a cost per ton basis at 18 to 19 knots on the long trade routes, and at 19 to 20 knots on routes as short as 12,000 miles round trip. Further improvement in the competitive position of the nuclear ships occurs in 1970.

After ore carriers, tankers are the next promising application for nuclear power in merchant ships. Large nuclear tankers in 1957 can carry cargo on 20,000-mile round-trip routes at lower unit cargo costs than conventionally powered tankers, at speeds higher than 22 knots. In 1965, the area of competitiveness for such ships will begin at 12,000-mile trade routes. By 1970, nuclear tankers will be more economic than conventional ships on 20,000-mile trade routes at any speed over 17 knots, and the larger nuclear tankers will be economically attractive on routes as short as 8,000 miles round trip.

Third in economic attractiveness for nuclear propulsion are general-cargo ships. Over the range of distances, speeds, and ship sizes analyzed, there is only one application in 1957 wherein the nuclear general-cargo ships with burtoning gear are economically competitive with their conventional counterparts. This application is on the 20,000-mile trade route at the fastest speeds for which these ships are designed. In 1965, there are applications both at 20,000 miles and 16,000 miles where competitive unit cargo costs are attained by nuclear ships. General-cargo ships with rapid-cargo-handling facilities attain competitive operating costs at shorter trade route distances than do the general-cargo ships with burtoning gear.

Nuclear passenger ships are competitive in 1957 at round-trip distances of 16,000 to 20,000 miles. The breakeven point is achieved first with the smallest ship. In 1965 and 1970, a trend to slower speeds is observed, as far as the breakeven point is concerned. Again, the smallest ship in any given trade route combination is economically the best application for nuclear power.

The nuclear passenger-cargo ships analyzed do not achieve as low an operating cost as conventional ships, except in 1965 and 1970. At these times, there are only two applications at 20,000 miles where the breakeven point is attained, and these are attained only with the smallest ship size.

The particular nuclear propulsion systems which offer the earliest opportunity for achieving a competitive position with fossil-fuel-powered plants are the organic-moderated and boiling-water reactor systems. In all the cases mentioned above, these two types of reactor propulsion systems are the ones that are able to compete with conventional vessels. Both reactor types present a promising potential for the early economic introduction of nuclear technology into the field of merchant ship propulsion. From the standpoint of their comparative developmental status, the most attractive system for nuclear ships in the immediate future in the boiling-water reactor, and the most attractive system for the near future is the organic-moderated reactor.

Both of these reactor types achieve their high ranking due to their low cost of construction in comparison with the pressurized-water and gas-cooled reactors. Both the boiling-water and organic-moderated reactors are relatively simple in design in comparison with the pressurized-water and gas-cooled reactors and operate at lower pressures. Cost disadvantages of the pressurized-water reactor are its complexity and need for high operating pressures. The gas-cooled reactor is large in size, thus incurring higher capital costs.

In general, nuclear ships are increasingly more competitive as compared with conventional ships as trade-route length and speed increases. This results from the fact that nuclear propulsion plants can deliver large amounts of power and travel great distances without sacrificing cargo space for fuel requirement. In addition, as the amount of power required increases, nuclear fuel costs become lower in relation to conventional fuels.

It is recommended that detailed design studies of ore carriers and tankers powered with organic-moderated and boiling-water reactor systems be initiated. These ships should be designed specifically for nuclear power, rather than as conversions or modifications of existing ships.

UNCONVENTIONAL METHODS FOR GENERATING ELECTRICITY

Radioisotope Devices

In the fission process, approximately 5 per cent of the total fission energy appears as excitation of the fission products. These radioactive isotopes release their energy of excitation by the emission of either gamma rays or beta particles as they return to stable isotopes. Since some of these radioactive isotopes decay with a half life of many years, this form of energy may be useful as a power source.

This source of energy can amount to only a small fraction of the total fission energy. In the McKinney report, January 1956, it was estimated that the United States nuclear-power industry would have an estimated installed capacity of 84,000 thermal megawatts by 1975. The corresponding rate of energy production in the form of usable radioactive isotopes would be about .05 per cent of this, or 50 Mw.[1]* This amount is only 1/100 that in all fission products, because few of the more than 200 radioisotopic species produced in fission are suitable for producing power for reasonable periods. Fission products with a half life shorter than 100 days are unsuitable for any reasonable life requirement and, to keep the heat source reasonably small, the radioisotope in its pure state must have a specific power of at least 0.01 watt per gram. Applying these criteria narrows the field of applicable radioisotopes rapidly.[1]

Isotopic energy sources have several other important inherent characteristics which limit their application:

(1) They must be separated from the radioactive waste of reactors and obtained in a pure form. This results in an expensive fuel and limits the quantities available from reactor power production and waste-processing facilities. For example, reports by the Martin Company personnel estimate that the cost of a 1-kilowatt strontium-90 power source, the largest size presently

*References for this section appear on page 60.

contemplated, would be about $438,000, so the power cost is $5/Kwh if used for a 10-year period.[2] The present annual Oak Ridge National Laboratory plant capacity is 1100 thermal watts.[1]

(2) They must be contained during life from the considerable biological hazards of a spill, since millions of curies of radioactivity are required for 1 kilowatt of electricity.

These factors point toward the use of radioisotope power sources in applications requiring small amounts of power, compactness, light weight, long life, and freedom from attention and maintenance. The peaceful applications which have been suggested as having such needs are warning beacons, navigational aids, remote weather stations, and auxiliary power supplies for small space vehicles.[3]

A leader in the development of devices for converting radioactive isotopic energy into electrical energy is The Martin Company through its SNAP-III program.[1,2,3] In this program devices of 1-watt power output have been developed using Po^{210} and Ce^{144} as heat sources to power a thermoelectric converter. Sr^{90} as well as other isotopes are under consideration. The present effort has been devoted primarily to proof-of-principle devices. Conversion efficiencies are in the range of 5 to 6 per cent, although it is expected that efficiencies up to 8.3 per cent may be obtained for power packs operating in the sea.[2] Martin Company personnel believe that power packs in the range of 5 to 500 watts of electrical energy can be built today.[2] Within 2 years the range will be expanded to include units developing 1 kilowatt of electricity.

Evaluation

It is apparent that, while radioisotopes will not be large energy sources, they can have a useful role in applications where their unique characteristics are needed. These are as small-power, compact, light and extremely reliable batteries. The need for batteries of this type is most apparent in Governmental functions (e.g., military,

navigational, and space agencies, etc.) and thus it is expected that their development will be stimulated naturally from this direction. Furthermore, it is expected that as these devices are developed for these applications, United States industry will be quick to promote their use in any domestic or world markets that may develop.

In summary, it is believed that the impact of radioisotope energy sources on the international atomic-energy scene is and will be minor, and that an international market for these unique power sources, if it comes into being, will develop through normal commercial channels. Accordingly, it appears that explicit action on the part of the U.S. Government toward additional research and development as a part of our international program in this area need not be taken at this time.

Devices Using Fission Energy

Within the past several years a considerable amount of attention has been given to so-called "direct conversion" devices as a means of converting nuclear energy to electrical energy. Most of this effort has been devoted to schemes which consider nuclear energy as heat energy and transduce this heat directly into electrical energy without passing through a mechanical-to-electrical transformation. For completeness it should be mentioned that several people have or are considering a method of converting the kinetic energy of the fission fragments directly into electrical energy, and some of this work has been reported in the literature.[4] However, these latter studies are all in a very preliminary form and it is impossible to evaluate their potential importance in regard to the objectives of this report. Accordingly, the remainder of the discussion of this section will be devoted to the ideas and the development of devices which convert heat energy into electrical energy. These are thermoelectric, thermionic, and

magnetohydrodynamic devices. The principles of operation of these various devices have been well described elsewhere and will not be covered here.*

Status

From the standpoint of utilizing energy from nuclear reactors, two of the three suggested conversion methods, thermoelectric and thermionic, have received the bulk of the research and development effort. In the most basic sense these methods are the same in principle; however in practice each has its own limitations, problems and performance potential.

Thermoelectric Conversion Methods

Thermoelectric devices utilize the well-known thermocouple principle, whereby a voltage is generated when there is a temperature difference between the junctions of two dissimilar materials connected in series. The principle has achieved perhaps its most common acceptance in thermostatic control devices.

Angello has stated that "The physics of thermoelectricity is now reasonably well understood and the theory indicates that efficiencies as high as 35 per cent to 40 per cent might be achieved".(5) However, to achieve this efficiency requires materials having physical properties not possessed by materials now known. Actual efficiencies to date with small units heated with fossil fuel are in the range of 6 per cent, with a theoretical upper limit of about 17 per cent.(5) Unit sizes in the range of 100 watts have been constructed and operated.

Present concepts of the application of this method of conversion to nuclear reactors visualize a primary coolant flowing through the reactor core where heat is received and transferred to the thermoelectric conversion unit out-of-pile. Ultimately, it has been anticipated that thermoelectric units might be placed directly in-pile. However, the

*A very good nontechnical description of the operation of thermoelectric and thermionic conversion is given in a paper entitled "Significance of Direct Energy Conversion" by Paul H. Egli, presented to the Joint Committee on Atomic Energy, Subcommittee on Research and Development Hearings on Frontiers in Atomic Energy Research, March 22-25, 1960.

technical feasibility of such a concept has not been demonstrated, especially as regards radiation-damage effects in the thermoelectric material. It is considered that the practical upper temperature limit for thermoelectric devices is about 1200 C (2192 F). Insofar as is known, no reactor development program utilizing thermoelectric conversion is currently in progress.

Thermionic Conversion Methods

Thermionic converters are based upon the principle that electric power is generated when a hot cathode is connected through a load to a cold anode under conditions such that electron flow between the electrodes occurs. One concept visualizes electron flow through a vacuum between anode and cathode. The other main concept receiving attention involves the use of a plasma between the anode and cathode. (The Los Alamos plasma thermocouple.)

Both of these concepts have been tried out in small-scale laboratory experiments.[6,7] By far the most serious attention is being paid to the plasma thermocouple. About 10 months ago a unit was operated for a short time in the Omega West Reactor at Los Alamos. This experiment produced 30 watts' electrical output, an emf of 4 volts open circuit, and a short-circuit current of 40 amperes.

The present concept of thermionic devices requires cathode temperatures in the range of 4000 F to 5000 F. This temperature requirement results from the combined need to obtain reasonable power densities, efficiencies, and sufficient cesium plasma ionization. Under these temperature conditions, and assuming that materials are structurally perfect, efficiencies in the range of 40 to 45 per cent are theoretically possible. Efficiencies of up to 13 per cent have been demonstrated for brief periods in the laboratory, but great difficulties will be encountered in producing a useful long-lived device which can operate at these high temperatures. The best that is available today is a small close-spaced diode with an efficiency of 2 per cent.[8]

On the basis of published reports, the largest effort toward the development of the plasma-thermocouple concept is being carried out at Los Alamos Scientific Laboratory; active research work is also under way at the General Atomics Division of the General Dynamics Corporation and at Livermore. Other industrial firms are believed to be interested in this concept but the type and extent of their effort is not known.

The origin of the plasma-thermocouple concept and the current effort was stimulated by the need for a nuclear power supply in space applications. Reactor concepts utilizing arrays of plasma thermocouples have been proposed. In this application, the concept has large potential advantages over more conventional power conversion equipment owing to the lack of rotating machinery (for improved reliability) and the possibility of exhausting heat at a high temperature (for reduced radiator weight).

In brief, the proof-of-principle of the plasma thermocouple has been demonstrated. Technical feasibility of a practical device either in a simple cell or in a reactor core configuration has not been established; however, work in this direction is in progress.

Magnetohydrodynamic Conversion Methods

In the past year, two industrial firms have announced the successful results of preliminary experiments utilizing the principles of magnetohydrodynamics to convert the velocity head of a partially ionized gas into electrical energy.[9] These principles are not new; they were discovered by Faraday around 1838 and form one of the cornerstones of all electrical energy devices. Essentially the current novelty involves the fact that if a gas is hot enough it becomes partially ionized. As a plasma it is a conducting fluid. Consequently when this conducting fluid is passed through a transverse magnetic field an electric potential is generated at right angles to both the magnetic field and the direction of fluid flow. If such an electrically conducting fluid is compressible, it can be expanded to do work against the magnetic field as compared with the more conventional means of

being expanded to perform work against the blades of a rotating turbine. Thus, the magnetic field essentially replaces the turbine blades.

Conducting, compressible fluids, as presently visualized, must be gases at very high temperatures (in the range of 3000 F). Accordingly, devices based upon this principle must be capable of handling these very-high-temperature gases, including the source required to heat the working fluid.

At the present time, the experiments reported have shown that a gas may be made into a plasma at sufficiently high temperatures and that, under the right conditions, electrical energy can be generated by a working fluid being expanded from a high to a low pressure. Thus the current status indicates that proof-of-principle has been established. However, practical technical feasibility has not been demonstrated.

Evaluation

The three basic direct-conversion schemes outlined above have several requirements in common which must be met in order to achieve basic technical feasibility as electrical-power-generating methods of practical size:

(1) High-temperature fuel materials.

To achieve efficiencies approaching those of a modern conventional steam-generating plant, fuel-element surface temperatures in excess of 2000 F are required. This is considerably higher than the capability of presently practical fuel elements.

(2) Radiation resistance

Concomitant with high-temperature capability, the fuel elements in each case must maintain their unique properties (e.g., electrical, thermal conductivity, emission, etc.) as well as structural integrity under high-burn-up conditions.

(3) Low-cost fuel cycle

This requirement is obvious and ever present in the competition of nuclear fuels with fossil fuels.

Considering the present technology of nuclear fuels, it is apparent that these requirements present enormous technical difficulties to be overcome. To do this, if it can be done, would appear to require a very large research and development effort.

There are other questions which also need to be considered. All of these devices simply convert thermal energy directly to electrical energy. Atomic energy has no unique advantages over fossil fuel as a source of heat, except as it can provide higher temperatures. Since it is an open question whether extreme temperatures are feasible for long periods of time, it may be that atomic energy has no unique practical advantages over fossil fuel, in utilizing direct conversion for central-station power generation. If atomic energy does not have a unique advantage, it must compete economically with fossil fuel, and in such a case it seems evident that reactor complexity must be minimized. The devices proposed would not seem to be a step in the direction of reactor simplicity.

Another factor is the radiation effects on the special materials sometimes needed. Such effects are now largely unexplored, and it is not known whether they will be harmful, or possibly beneficial.

Still another factor is efficiency. Although the efficiency estimates are fairly high for extreme temperatures, the efficiency of heat engines working at such temperatures would be much higher if there were materials capable of operating at such temperatures. It is not necessarily easier to find nuclear materials capable of operating at such temperatures rather than conventional ones. In addition, while the estimated efficiencies are high, the realizable efficiency may not be in excess of those now achievable from modern steam plants, about 40 per cent.

The advantage of these devices is that they produce electricity without rotating machinery. For some applications, such as space vehicles, this is a real advantage. However, for central-station power applications, the low-voltage direct current needs to be converted to high-voltage alternating current, so that a part, perhaps a large part, of their advantage is lost.

When developed, devices of this type, or of other types of low-power electrical generating devices such as small reactors, may have applications of international significance. Such applications, for example, might be their use in satellites as relay stations for radio or television, for navigational purposes, or for weather surveying. Such applications were discussed by J. R. Wetch, before the Joint Committee on Atomic Energy hearings on March 24, 1960, on Frontiers on Atomic Energy Research.

The purpose of these remarks has been to point up the many unsolved problems of direct-conversion methods, not to minimize their potential. The methods may prove to have great utility in one or another application, but at present too little is known about them to permit any assessment of their future capabilities. As research and development proceed, the situation will be resolved.

The necessary research involves the development of materials having the required electrical characteristics and radiation damage resistance for thermoelectric and thermionic devices, and of materials which will withstand ultra-high temperatures, for thermionic and magnetohydrodynamic devices. Only when such research has been brought to a conclusion can their practical utility be estimated.

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INDUSTRIAL APPLICATION OF RADIOISOTOPES AND RADIATION

The information for this section was taken from an AEC status report and from very detailed information available from other reports and surveys. This information was supplemented by conferences with well-known workers in these fields. The sources of information are given at the end of this section, on pages 82-84.

Radioisotopes

Under this heading will be considered the uses of radioisotopes that are characterized by very low levels of radiation with no radiation-induced changes desired or expected.

Uses Presently Standard and Widely Adopted

Radioisotopes for some uses have achieved widespread acceptance and adoption and are playing an important part in present-day industry in the United States. These fall, in general, under four main classifications: (1) gaging and testing, (2) tracing, (3) research, and (4) inspection.

Gaging and Testing Applications. In gaging and testing are included thickness gages, gages for the determination of density of both solid and liquid materials, and liquid-level gages or, more broadly, those designed to find the interface between two phases. Thickness gages are used to determine the total thickness of a uniform material or to determine the thickness of a coating on some base material. The principle of operation is simple: A source is placed on one side of the material to be measured and a radiation detector on the other side. The magnitude of the radiation received is directly related to the mass thickness of the material. Because the output of the radiation-measuring device is usually electrical in nature, it is relatively simple and quite common to use the reading of this instrument to reset the controls that govern the

thickness of the material being examined, thus leading to automatic maintenance of the desired thickness. In the census conducted by the National Industrial Conference Board, there are listed 300 separate installations in which one or more thickness gages are now in normal industrial use.

Perhaps a better measure is the fraction of a given application that is already converted to radiation-type thickness gages. It is estimated that 60 per cent of the cold-rolling mills of major steel producers are so equipped, and perhaps 50 per cent of the hot-rolling mills, although these are primarily X-ray.

In the rubber industry, probably 90 per cent of tire calenders in the larger plants make use of β-ray thickness gages and 30 per cent of the specialty calendering.

In paper making and boxboard making, about one-fourth of the major plants are equipped, and in paper converting and laminating, probably one-half.

Although no figures are available, it is fair to estimate that three-quarters of the cigarette-making machines are equipped with density gages.

As the benefits of these installations become known, and as applications to new industries or processes are developed, it can be expected that the use of radioisotopic thickness gaging will increase steadily to a level presumably many times the present magnitude.

Liquid-level gages normally work on the difference in density between the liquid whose level is being measured and the air or vapor space above the liquid. Again, these gages consist of a radioisotope source and a radiation-detection device. Both may be mounted within the vessel or on the outside. Since the source can be chosen to give radiation that will penetrate the vessel walls, these gages are especially important under demanding circumstances when conventional float-type gages, gage glasses, or other simple gaging devices are not practical. Only a modest number are reported at present, but it can be anticipated that their use will become more widespread under circumstances that justify the usually increased costs over standard methods of gaging.

Density gages will measure the density of solids, liquids, slurries, or gaseous suspensions of solids. The thickness of the moving material is held constant and, thus, the radiation received by the detector decreases as the density is increased. A wide range of materials is measured or controlled by this means, ranging from the well-known determination of cigarette firmness to measurements of the density of hot and highly corrosive slurries very difficult to measure by other means. The National Industrial Conference Board census reports almost 70 such installations and again it is expected that, as the knowledge of these installations is extended and the development of specialized installations proceeds, their use will be markedly increased.

The savings from the use of radioisotopes have been given in several estimates, which varied widely. That given in the 1956 report on the Peaceful Uses of Atomic Energy was $100 million, plus or minus 50 per cent. To resolve uncertainties, the AEC requested the National Industrial Conference Board to conduct a survey, to obtain a better estimate of the savings to industry from the use of radioisotopes. Of the total annual savings of $39 million reported in the census, almos $19 million was credited to gaging applications broadly. Petroleum refining, tobacco, rubber, paper, primary metals, plastics and resins, and chemicals were largest in that order. Within this group, the estimated savings ranged from over $4 million to $1-1/4 million. The plastics and synthetic-resins companies reported a total saving of $1,385,000 – all due to thickness gaging of plastic film. Table 1 summarizes these data.

It is quite probable that many of the savings actually achieved would not be reported in such a census for a variety of reasons. Such unreported benefits might change the order of the industries given above as well as change the magnitude of the dollar volume of savings. Perhaps if the NICB figures are taken as minimum, a truer appreciation of the situation may result.

TABLE 1. SUMMARY OF SAVINGS EFFECTED BY USE OF RADIOISOTOPES IN INDUSTRY[a]

(In thousand dollars)

	Gaging[b]	Radiography	Research	Manufacturing and Processing	Total
Petrol. Ref.	4,120	16	5,000	2,480	11,610
Chem.	1,250	75	2,300	800	4,450
Tobacco	2,950	--	--	--	2,900
Rubber	2,840	--	--	--	2,840
Paper	2,820	--	--	--	2,820
Prim. Metal.	1,450	760	30	--	2,240
Eng. Serv.	--	400	1,740	--	2,150
Trans. Equip.	280	690	750	10	1,730
Plastics and Resins	1,380	--	--	--	1,380
Drugs	--	--	810	190	1,000
Machinery	10	250	530	200	990
Stone, Clay, Glass	550	290	--	30	870
Crude Petrol.	41	11	--	810	820
Electronics	--	--	780	40	820
Food	30	--	180	580	800
Fab. Met. Prod.	--	600	20	--	620
Text. Mill Prod.	420	--	--	--	420
Elec. Mach.	170	10	100	10	290
Metal Mining	250	--	10	--	260
Totals[c]	18,590	2,800	12,640	5,170	39,200

(a) National Industrial Conference Board Report, "Radioisotopes in Industry" (1959).
(b) Unconfirmed statements concerning substantial savings achieved but not reported.
(c) Includes some not shown in table.

In many of the applications discussed above, standard commercial units are available for purchase. The determination of the economics of a particular installation is relatively simple. The benefits to be derived are usually those of raw-materials saving, convenience, improved operation, greater safety, or a closer approach to completely automatic control. Although their monetary value may be difficult to state in dollars and cents, the benefits resulting are usually clearly recognized and known usually to be worth many times the cost.

Tracing Application. The use of radioisotopes for tracing can be considered broadly as a means for following the movement of materials in one sense or another. The flow of oil through a pipeline, the migration of water through the soil, the removal of metal particles by wear or corrosion, the detection of leaks, and a host of others are examples of this technique. In general, not many of these are employed routinely in production processes, but in almost every industry they are extensively employed in research studies of these processes.

Unlike the gages, however, in general this method involves the addition of a radioactive material to some process stream or piece of equipment and thus makes necessary health and safety precautions specific to the particular use in question. This means that it is not possible to purchase a standard piece of equipment already designed to protect those in the area of use. It generally requires a means for storing and handling perhaps very low levels of radioactivity, and implies the availability of people trained in the use and handling of radioisotopes. As such, perhaps its use is more generally limited to those companies and industries that maintain some research facilities or that have access to them. It generally implies a little higher technical sophistication in conceiving and designing the necessary experimental setup. In spite of this, the possibility of accomplishing many things not practical otherwise can be expected to lead to continued expansion of the use of radioisotopes for this purpose. In some cases where alternative

methods of accomplishing the same purpose exist, it is possible to determine the monetary benefits resulting from the use of radioisotopes. In others, since there is no alternative method, the benefits however real sometimes cannot be evaluated.

The individual examples are too numerous and diverse to attempt to list or group, but the NICB census gives enough to indicate that almost every aspect of each industry considered is using or is a candidate for these tracing techniques in one way or another.

Research Applications. Under "research" the NICB lists savings amounting to over $12 million, about 30 per cent of the total reported. This, with gaging applications, accounts for 80 per cent of the total. Petroleum refining, chemicals, engineering services, drugs, electronics, transportation equipment, and machinery each reported savings of over $1/2 million per year. This ranged from $5 million for petroleum refining down to $1/2 million for machinery.

Two points should be made here. First, many of the savings reported are an estimate of research time that was saved. For example, in wear testing of a lubricating oil in auto engines in one case, the nonisotope method required 500 hours; the tracer method only 6 hours, with a calculated saving of $400,000 per year. This meant that the company could make many more tests per year with the same personnel and equipment, and the end result was not the saving of money but the procurement of much more information than would have been the case without isotopes.

Second, of the industries that report the largest benefits from the use of isotopes in gaging and in research, several are very-high-volume industries. Quite frequently the unit returns are very small, but, multiplied by a very large number of units per year, the annual savings are impressive. A petroleum refiner reported a saving of $500,000 per year in one application. This resulted from a saving of only 1/2 cent per barrel of oil processed, of which 100 million barrels are processed per year. The benefits are just as real, but this points up one factor present in many industrial uses of

radioisotopes. In general, their use does not result in revolutionary changes; they are new tools, extremely useful, but most frequently applied to cause a modest increase in the efficiency of an already efficient, large-scale operation.

Inspection Applications. Inspection is generally taken to mean inspection by radiograph; that is, the examination for voids, cracks, or thickness variations by virtue of the changes in intensity of radiation that is passed through the material under examination. There are a variety of techniques for accomplishing this, all of them closely similar to those used with X-rays. In many instances, there is an advantage for radioisotopes over X-rays by virtue of the fact that the source is generally more compact, more portable, and not dependent upon a power supply. The use of radiography is standard and widespread enough so that any discussion of the benefits to be achieved would be superfluous. The use of a radioisotope such as cobalt-60 as a substitute for an X-ray machine has advantages in many cases and these, in general, can be readily determined for each application. The NICB census lists almost 400 examples in 11 different industries of materials or objects that are routinely radiographed by isotopes. There is every reason to believe, of course, that this use of isotopes will be expanded. The benefits and the differences between this and existing techniques are less than in the applications discussed earlier.

Types of Research Which Might Expand Present Uses of Radioisotopes

Many of the purposes for which isotopes are presently being used are alternative to older, more widely known methods for at least approximating the same result. Since there is quite uniformly a resistance to change, it is almost certain that an industry-by-industry or process-by-process study would turn up many new applications for isotopes in gaging and testing, in tracing, and, to a lesser extent, in inspection. Research and development on the fabrication and shielding of isotope sources, the development of

radiation detectors that are simpler, more compact, more reliable, more precise, or less expensive would obviously tend to increase the extent to which isotopes are used. The availability of a wider range of "tagged" materials and the widespread availability of research and test reactors in which machined parts and specimens could be made radioactive would also lead to an extension of isotope use. As was mentioned above, the output of the radiation detector is usually in the form of an electrical signal which then can be further used for process-control purposes. Another fruitful area of study would be one aimed at uncovering unusual possibilities for more extensive or complete automation. Ancillary to this, of course, would be the development of control devices specifically designed to work in such systems.

Application to Other Countries

Technically and industrially the United States is probably the most sophisticated country in the world and in most areas its industries operate on a scale many times that of any country with the possible exception of Russia. The managements of our companies are prepared to make substantial investments in plant equipment and controls that will lead to better, cheaper, or more reliable operation. Most of the industrial concerns of any appreciable size in the United States have their own or make use of research organizations. In such an environment, the expansion of the use of radioisotopes for these purposes at an appreciable and perhaps an accelerated rate is to be expected.

To a lesser degree, this is also true for those countries outside the United States which have achieved a technical or industrial sophistication approaching that of the United States. In general, size of the country is not so much a consideration as the state of its industrial development. In many cases these are the countries that are in serious competition for world markets, and the increases in efficiency that these and other advances may bring about sometimes will provide the margin by which to offset the greater material wealth or industrial size of the United States. It can be expected that the drive

for improved efficiency will provide a real stimulus for the adoption of radioisotopes as rapidly as the country's capability will permit.

For countries less highly industrialized, it could be expected that the simpler applications of isotope use might expand by using on an increasing scale the application of sealed sources to gaging of one kind or another, but that the widespread research and development use of tracer techniques would have to be preceded by an expansion of research facilities, means by which the required tagged materials might become available, and the development of health and safety knowledge and experience that would make such use safe.

Another prerequisite would be the existence, in the technical community, of sufficient awareness of and general familiarity with the broad kinds of usefulness of isotopes to stimulate the perception of possible applications to the problems of the industries represented. This implies the necessity of general indoctrination of technical personnel, plus a certain minimum concentration of people specifically trained in the mechanics of use of isotopes.

Over and beyond all else, there will be necessary some education of top executives and management in the benefits to be derived from isotopes use in their businesses, to create a climate favorable to the technical recommendations for application to a specific problem. This should not be in terms of the "brave new world" concept, but rather on the basis of quite prosaic, however new, tools that can be expected to make modest contributions to efficiency of plant operations.

Formal training will be required for those who will plan, set up, and supervise these applications. However, progress in isotope utilization probably will be helped considerably by the widespread dissemination of information regarding uses already in being elsewhere. A "case history" approach discussing the problem and its implications, the alternative attacks, the advantages and disadvantages of isotopes, the method, the result, and any extrapolation of this case to others might be stimulating.

It would seem that acceleration of the rate of employment of radioisotopes in all but the most industrialized countries might be achieved by expanding the facilities for formal training and education in this area, and the initiation of an extensive program of information dissemination aimed especially at management and technical personnel.

Uses of Radiation

The primary industrial interest in massive doses of radiation is in the application of inducing chemical reactions. Ionizing radiation, as its name implies, can create excited or activated states of atoms or molecules which, after excitation, react more readily and in some instances undergo reactions that otherwise would not occur. It is possible to create these excited states by means other than radiation, such as heat, light, or catalysis, so that frequently the use of one agent or the other is a question only of convenience or cost.

Effect of Radiation on Chemical Reactions

The effectiveness of radiation for inducing a given reaction is generally expressed as the "G" value, which is the number of molecules reacting or formed per 100 electron-volts of radiation energy dissipated in the material. For most reactions this value ranges from substantially zero up to about 5. However, some reactions, if once started, proceed with little or no additional energy input. Since it is necessary only to start the first step in a chain, the total number of molecules reacting per 100 ev can be very high, as much as 50,000. Some of these reactions can also be "triggered" by means such as ultraviolet light, heat, electricity, or other forms of energy. G values for a few illustrative chemical reactions are given in Table 2.

The yield of product per unit of radiation energy obviously goes up as the G value is increased. Further, since this expresses the number of molecules that react per 100 electron-volts, the weight yield of product increases with the molecular weight. The

most commonly used unit of energy is the kilowatt-hour, and the effectiveness of radiation utilization can be expressed in the following way:

$$\text{Pounds Product per Kwhr} = \frac{G \times \text{Molecular Weight}}{1220}$$

The radiation energy requirements for various reactions have been calculated and the data are given in Table 2. Later in this discussion, it will be shown that the cost of radiation energy is high at present – $1 to $10 per kilowatt-hour. With such high energy costs, it is evidently uneconomic to use radiation to activate most of the chemical reactions illustrated in Table 2. For this reason, much of the research to date has been directed toward seeking reactions that have a high product of G values and molecular weight, to reduce the cost of radiation energy.

A second consideration in achieving economy is that the production of a material by conventional means should be high in cost or perhaps impossible to achieve at present. A third is that the product should have a high value.

TABLE 2. REACTIONS INDUCED BY IONIZING RADIATION

Reaction	G Value	Kwhr/Lb Product
Chlorination of benzene		
$C_6H_6 + 3Cl_2 \rightarrow C_6H_6Cl_6$	85,000 (est.)	0.0005 (all isomers)
Fixation of nitrogen		
$N_2 + O_2 \rightarrow 2NO$		
$2NO + O_2 \rightarrow 2NO_2$	6 (est.)	4.4
Synthesis of ethylene glycol from methanol		
$2CH_3OH \rightarrow C_2H_4(OH)_2 + H_2$	3	12.2
Oxidation of benzene to phenol		
$C_6H_6 + 1/2O_2 \xrightarrow{(H_2O)} C_6H_5OH$	50	0.3

Research in Progress

A moderately large amount of exploratory research has been carried out thus far. Quite largely this has been a scanning type of effort, looking for high product yields, important effects not achievable otherwise, or an application of such high value that the cost of radiation would not be a controlling economic factor.

So far as is known, none of these searches has yet been successful. It seems that the character of the research effort is now changing – settling down in many cases to a systematic search for potentially useful information in this field – in other cases, to a major reduction in the level of effort.

It must be recognized that much industrial research is defensive. It is undertaken primarily to decrease the chances that a company's competitors will achieve a major advantage through an important invention. As a scanning effort progresses without finding any leads to such a major invention, the competitive threat diminishes, and the incentive for further defensive research begins to lessen. In many industries, that has occurred in the field of radiation-induced changes.

The "agressive" research is undertaken in the belief that new knowledge in the field in question will eventually be of benefit to the company's operations.

Apparently there is a reasonable amount of research activity of this character, and future prospects depend upon the results of this research. Favorable developments will lead to continuous expansion of this research. However, in the event that there is little progress in reduction of radiation cost and in discovery of promising reactions, then probably radiation will be relegated to the position of a useful tool for research in other areas, but commanding little importance as a precursor of industrial processes.

It has been said, "Radiation faces stiff competition in industry. In cases where radiation could open the door to a new process or product the industrial scientists would strive for, and frequently find, ways and means for achieving the same result with

conventional tools – heat, pressure, catalysts, etc., thus minimizing, or eliminating, advantages radiation gave over the older conventional method."*

Economic Factors

Many of the effects of radiation can be achieved by other means such as heat, pressure, electrical energy, or catalysis. If important effects are discovered that cannot be achieved by any other means, the cost of the irradiation may not be the most important factor. But in the cases where some other means is effective, the cost of achieving the desired result by radiation must be competitive with the alternative method.

Thus far, some applications have been found in which no other means is yet available. Unless a larger number of such applications are found, the prospects for widespread industrial use of atomic energy will depend on achieving radiation-processing costs that are competitive.

The radiation necessary for these processes can be obtained from massive isotope sources, machine generators such as X-ray machines or accelerators, the gamma radiation from a power reactor, or the recoil energy of fission fragments in a reactor built primarily for processing purposes.

At the present time, radiation from isotope sources or machines is estimated to cost from $1 to $10 per kilowatt-hour. Where other forms of energy can be used in processing with equal efficiency, the cost of radiation must be reduced by one to two orders of magnitude, unless uses can be found in which the efficiency of utilization of absorbed radiation energy is very high. If a useful reaction were found in which the G value was as high as the 50,000 mentioned earlier in this section, and the product molecular weight was 5,000, then 200,000 pounds of product would be produced per kilowatt-hour. In such a case, an energy price of even $10 per kwhr would amount to

*"A Management Evaluation of Massive Radiation for Industrial Utilization", AECU-4240, May 11, 1959, p 25.

only 10 cents per ton of product! A process like this would be very attractive at present radiation costs.

However, such an application would not require a large energy source. If a 10-kw source was used in this case, the production would be 10 x 205,000, or over 2 million pounds per hour – about 25,000 tons per day. Reactions with such a high G value are not common, and the total radiation capability required for these cases would be small. On the other hand, the value of the product might well be great.

The G values for most reactions range up to about 5, and the molecular weights of many products of industrial interest are of the order of a few hundred or less. If G were 5 and molecular weight 100, then the pounds of product per kwhr would be

$$\frac{5 \times 100}{1220} = 0.41.$$

Present radiation costs would be excessive for normal industrial products. Even if radiation costs were reduced to 1 cent per kwhr, the charge would still be 2.5 cents per pound of product for the energy alone. The product would have to be a relatively high-priced one, and perhaps one that could not readily be made by other methods, to justify the use of radiation.

Thus, if the efficiency of radiation utilization is abnormally high, the amount of radiation required is small; if the efficiency is normal, radiation costs are overridingly important. It would seem, then, that for any widespread industrial application of radiation, energy costs must be reduced to a small fraction of the current level, and reactions must be found in which the product of G value and molecular weight are at least one or more orders or magnitude higher than those of most reactions, or ways must be found to increase the G value of reactions for which it is now too low.

Current Uses of Radiation

A few uses have been developed on a limited scale and a few are reported to be past the laboratory stage but not yet in production.

The irradiation of polyethylene to promote cross-linking and thus to yield a non-melting polymer for use as special electrical insulation was put into commercial operation about 1955. Since its inception, high-density polyethylenes produced by nonnuclear means have exhibited comparable qualities, and at least one company has succeeded in cross-linking by chemical means. It remains to be seen how severe is the economic competition which the radiation-produced material will face.

By graft polymerization under irradiation, a Teflon modification has been developed that is dyeable. This material was specifically produced to meet some military needs, and no substantial civilian market is yet foreseen for a dyeable Teflon.

At least one company is now engaged in the sterilization of sutures and probably other surgical materials by means of radiation. This has several advantages over high-temperature sterilization and presumably will expand somewhat in use. However, the market for such material is not extensive.

One company has reported that a process for radiation-induced graft polymerization has moved into the development stage. The product is a semipermeable membrane for dialysis, which might have application for the desalting of sea water.

Three or four companies have reported unspecified projects now under engineering development. The pilot-plant requirements of one of these projects could be met by a 3-kw electron accelerator. Several more radiation applications have been reported (again not identified) as potentially attractive if and when the cost of radiation is reduced by one or two orders of magnitude.

Radiation Costs

It would seem then that fulfillment of the promise of large-scale use of radiation in processing will be greatly dependent on the possibilities of reduction of the cost of radiation. The sources presently considered for industrial purposes are:

(1) Radioisotopes such as cobalt-60 and cesium-137

(2) Machine generators – resonant transformer, linear accelerator, and Van de Graaff.

(3) Gamma radiation derived from a reactor either built exclusively for this purpose or designed also to generate steam for electric power production

(4) Recoil energy of fragments from fission occurring in a reactor probably built exclusively for this purpose. Reactants will be in the core itself and fission products normally will be present in the reaction product stream.

(Spent fuel elements and gross fission products have been considered, but substantially every study made indicated that these would be higher in over-all costs than those listed above for an industrial use of any magnitude.

It is difficult and expensive to maintain a gross fission product radiation source at full and uniform power. The radioactivity decays rather rapidly even after 6 months' aging, and the specific activity severely affects the radiation geometry and capacity of the source. Also, the generation of heat, especially by beta emitters, poses significant engineering problems in radiation source designs. Calcining the crude wastes to give higher specific activity and ease of handling is currently under study, but the costs of calcining and containment cannot yet be estimated. In any case, the other undesirable factors – rapid decay and heat generation – remain.)

For many reactions, these sources will be interchangeable, and the choice will be dependent on the size of source required, radiation cost in that source size, applicability to processing environment required, susceptibility of process stream to activation, ease of decontamination, and others.

Present costs for the first two are fairly well known in moderate size ranges, and perhaps can be extrapolated to a period when production of multikilowatt sources would have been achieved. Any operating costs are heavily dependent on the method of handling fixed charges and, when capital costs are high, on the load factor.

Estimates made on the basis of 10-year depreciation, 8400-hour-per-year operation (96 per cent load factor), no return on capital investment for Co^{60} and Cs^{137}, and machine generators, each at 3-kw and 30-kw output, show the following total costs in dollars per kwhr of radiation output:

	3 kw	30 kw
Co^{60}	6.60(1)	1.90(2)
Cs^{137}	7.00(3)	2.50(4)
Machine generator	6.95	1.40(5)

(1) Assumes cost of $0.75/curie
(2) Assumes cost of $0.50/curie
} Present price $2.80 at 20-40 curies/gram

(3) Assumes cost of $0.25/curie
(4) Assumes cost of $0.15/curie
} Present price not significant, production from pilot plant only

(5) Assumes purchase price at $10,000/kw for two 15-kw machines. Estimates range down to $5,000/kw for 50-kw machines.

The Martin Company and Air Reduction Company, Incorporated, have disclosed discussions of a joint venture looking to possible construction, at some future date, of a $10 to 12 million production plant for the separation of strontium-90, cesium-137, cerium-144, and promethium-147. Joint studies are incomplete but have indicated to date, according to J. Donald Rauth, Martin Vice President, that strontium-90 could be produced in megacurie quantities at one-tenth current prices, or 35 to 50 cents per curie. Martin officials say the plant would not be scheduled, however, until some sort

of long-range commitment was forthcoming from the Government – for Sr^{90}, for example, to meet isotopic-power requirements.

Such a facility, for whatever reason constructed, could be expected to advance considerably some phases of isotope availability and utilization.

The foregoing would indicate that there is promise of cost reduction to something in the $1 to $2 per kwhr range for either machine or isotope sources, but that reductions beyond this are not likely except by some major development in the future. Certainly, the hope for large reductions in radiation costs lies with the nuclear reactor.

Reactor radiations might be performed in one of three ways:

(1) The processing might be carried on outside the reactor. Strong gamma radiation could be supplied by fluid activated by neutrons in the reactor, then circulated through an irradiator in proximity to the process vessel, and back to the reactor for reactivation. This fluid could be the reactor coolant, or another fluid in a special circuit for this purpose. Molten sodium in one case and indium sulfate solutions, in another, have been proposed for this use. If the processing is carried on outside the neutron shielding, activation of the chemical systems should not be a problem.

It is possible to make a rough estimate of the cost of radiation from such a source. It is reasonable to estimate that one might approach as a limit the capturing of one-half neutron per fission in the fluid being activated, and that one could approach 1 mev energy in the gamma given off from the activated species. Per fission, the gamma energy would be 1/2 mev, while the fission (heat) energy approaches 200 mev.

Thus, to obtain a 1-megawatt gamma source, one would need to operate a 400-Mw (thermal) reactor. If we assume first that this plant is operated only for the gamma energy of the activated source, and the heat is dumped without cost, one can estimate from the AEC status

report on noncentral-station reactors that the gamma energy would cost 50 cents per kwhr.* This cost is not enough less than that of isotope sources to permit a large increase in the industrial use of radiation.

This estimate is far below that made in detailed studies, where estimates have been made that radiation costs would be $5 per kilowatt-hour. Undoubtedly our estimate represents an optimistic lower limit for this type of reactor radiation costs.

Such a system might be installed on a reactor operated primarily for electric-power generation, in which case only a part of the costs would be charged against the chemical operation. For an example, from data given in the AEC status report for a sodium-cooled reactor power station generating 250 megawatts (thermal), or 75 megawatts of electricity, it can be found that the sodium can develop about 100 kw of gamma energy. If only 10 cents per kwhr were charged for the gamma energy, the gamma energy would yield a revenue of only $240 per day, or about 0.13 mil per kwhr of electricity produced, even with the optimistic assumption of 100 per cent gamma absorption in the material being irradiated. It is doubtful whether the operator of a reactor being operated primarily for electric power would tolerate the added complexity for so little gain.

If a charge were made of $1 per kwhr of gamma energy, a value which isotope sources may approach, the profit realized by the reactor operator would be 1.3 mils per kwhr, which is an amount that begins to be attractive to a reactor operator.

*Estimate is based on data given in status report on steam cost of 37 cents per million Btu (1.26 mils per kwhr) for steam from a 370 thermal Mw plant for producing potable water from sea water. Cost might be a little lower if a pressure vessel were not required, but this would be compensated for by the use of more highly enriched uranium required to permit capture of 0.5 neutron per fission in the gamma source.

It is apparent that the charge for energy in a case like this would be dependent, not on the cost of producing the energy, but on the income that would persuade the power plant operator to accept the complications imposed by the addition of the chemical operation. However, no very large reduction of gamma-energy cost appears likely.

(2) The chemical process vessel or system might be installed in the reactor core. In such a case, the core gamma and neutron radiation theoretically available would be of the order of 6 per cent of the total core power. Cost estimates made for a 40-Mw thermal process-heat reactor indicate a total operating cost of $132 per hour. The cost would not be much less if the pressure vessel were not required, because other means of dumping heat would be required. Such a reactor theoretically would produce 2400 kw of radiation. The cost here would be about 5.5 cents per kwhr, if provision for the chemical process system in the reactor core did not add appreciably to the capital or operating costs of the reactor. The special problems associated with this type of radiation are maintaining the desired process environment, temperature, etc.; providing for process control and instrumentation in the irradiation field; servicing the process equipment; and, most important, coping with the radioactivation of the process stream. Solutions would need to be found for these, and economic comparisons would need to include any added cost imposed by the solutions chosen. The situation can be very complex, especially if the reactor is used for both heat and gamma energy.

(3) The nuclear fuel itself may be in the process stream. In this way, the fission fragment recoil energy can be applied to the process reaction.

A 3-megawatt reactor would probably supply 2400 kw of radiation power. Costs for such a reactor cannot be estimated now because such systems have not gone beyond the conceptual design stage, and technical feasibility has not yet been established. But, if the reactor cost $250,000 per year to operate*, the energy cost would be 1-1/3 cents per kwhr. Here the decontamination problem would be most severe because the process stream would probably contain substantially all of the fission products, as well as activated process species. At the present time opinion is sharply divided concerning the feasibility of such decontamination, but there is little doubt that its achievement is essential to the success of such a system.

Such a reactor is a fairly large radiation source for all but very large volume, very low cost, heavy chemicals which are unlikely to be able to afford projected radiation costs. It would, for example supply over half the country's requirements for phenol.

Areas of Research

As stated above, industrial research probably will continue to develop a background of both general and specific information regarding the effect of radiation on chemical reactions. The search for ways of achieving high G values, products not obtainable otherwise, and high-value products should be supplemented by more fundamental investigations regarding identity of activated species and mechanisms of reaction.

The development of improved particle-beam generators is another area of interest. Research on the use of reactor-generated radiation is an obvious necessity. Means of integrating a process-radiation source into a power- or heat-generating reactor should be a part of the study of each reactor system showing promise. The development of

*A pool-type research reactor will cost this much to operate, and it is not expected that the chemonuclear reactor will cost less.

concepts of reactors using fragment recoil energy, and especially studies of decontamination of process streams – both from fission wastes and activated process species – are most important. Development of instrument and control systems effective in a radiation environment would also be of benefit to the ultimate achievement of a chemonuclear reactor.

Impact on Other Countries

It is expected that research will go on in other countries that have a substantial reactor development and power-generation program, on finding useful chemical reactions with high G values, studying ways of increasing the G value of reactions already investigated, and thorough study of the decontamination of products radiated in-pile by gamma rays and neutrons or fission fragments. Nonindustrial countries are expected to benefit little from this application of radiation.

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NUCLEAR EXPLOSIVES

A possible application of atomic energy for peacetime purposes is to use the energy released during the explosion of a nuclear device. Project Plowshare, now 2 years old, has been directed toward investigating the peacetime uses of nuclear explosives fired underground. To this end, it has studied in detail eight blasts fired at different depths in the tuff of the Nevada Test Site. In addition, Plowshare has made many paper studies of possible applications of nuclear explosives.

These investigations are still in an early stage. Because of the limited experimental evidence available, and because of the unique properties and the special problems involved, the potential peacetime usefulness of nuclear explosives cannot be fully estimated at the present time.

Underground Nuclear Explosions

The experiments studied by Plowshare were intended to disclose the capabilities and limitations of nuclear explosives fired at different depths beneath the earth's surface. Table 1 shows the characteristics of these blasts. Prediction of the behavior of nuclear explosives in types of rock other than the volcanic tuff in which these shots were made is uncertain.

Earth Moving

The depth at which a nuclear explosive is fired controls the manner in which earth movement occurs. A measure of this depth which allows for the size of the explosion is the "scaled depth", determined by dividing the depth in feet where the explosion occurs by the cube root of the yield in kilotons. Where the scaled depth is 20 feet or less, the material excavated is pulverized to dust and almost entirely blown out of the crater. At a scaled depth of 65 feet there is an open crater and extensive crushing of the rock beneath the site of the explosion. Maximum crater volume occurs at a scaled depth of about

TABLE 1. CHARACTERISTICS OF UNDERGROUND NUCLEAR EXPLOSIONS IN NEVADA (31°N, 116°W)[a]

Experiment	Date	Yield, kilotons	Depth, feet	Scaled Depth, feet[b]	Radioactivity Escape, per cent	Crater Volume	
						Total, yd^3	Unit, yd^3/kt
Buster-Jangle (Uncle)	19 Nov 1951	1.2	17	16	50	37,000	31,000
Teapot (Ess)	23 Mar 1955	1.2	67	63	50	96,000	80,000
Neptume	14 Oct 1958	0.09	99	220	1-2	33,000	370,000
Blanca	30 Oct 1958	23	835	290	0.1-0.2	0	0
Logan	15 Oct 1958	4.5	830	500	0	0	0
Rainier	19 Sep 1957	1.7	790	670	0	0	0
Tamalpais	8 Oct 1958	0.06	330	840	0[c]	0	0
Evans	28 Oct 1958	0.05	840	2260	0[d]	0	0

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(b) Scaled depth = Depth (Ft)/Yield (kilotons)$^{1/3}$.

(c) No breakthrough to surface but radioactive materials leaked into tunnel.

(d) No breakthrough, but stemming failed, releasing fission activity into tunnel.

150 feet. Beyond a scaled depth of 300 feet, no open crater if formed and all the energy of the explosion is utilized in producing an underground cavity, crushing the rock surrounding it, and raising the temperature of the surroundings.

Thus, for earth moving, explosions at a scaled depth of about 150 feet will produce the largest crater.

Underground Action

In the case of the Rainier experiment where the scaled depth was 670 feet, there was no breakthrough of the explosion at the surface. A cavity 130 feet in radius was formed around the detonation point, lined with 4 inches of melted rock. Within a few seconds, the roof of this cavity collapsed by successive caving upward for about 400 feet, leaving a large cylindrical shaft above the detonation point filled with crushed rock. In this experiment, where the yield was 1.7 kilotons, the explosion crushed an estimated 500,000 tons of rock and the caving produced 200,000 tons of permeable rock. On this basis for Nevada tuff, crushed rock impermeable to water amounted to 300,000 tons per kiloton yield, and rock broken by caving added 120,000 tons per kiloton yield.

About half the total energy released, or more than 3 million Btu, was available above 400 F, at the time bore holes were sunk to measure temperature. Eighteen months later, the highest temperature observed was 194 F.

Characteristics of Nuclear Explosives

Nuclear explosives are unique compared with chemical explosives. They release larger quantities of energy than is feasible with chemical explosives, they release this energy a thousand times more rapidly than the fastest chemical detonations, and they contaminate their surroundings with radioactive wastes. Their most important characteristics for peacetime purposes are the heat released and the explosive work they can perform.

Heat Produced

Many suggestions have been made to utilize the heat released. Table 2 shows the cost of heat produced by nuclear explosives of different sizes, compared with the cost of heat produced from conventional fuels. It should be noted that these are the published prices, and that independent estimates have suggested that lower prices than these are more nearly correct. It is evident that heat from small nuclear devices is expensive, 50 to 100 times more than from conventional fuels. Even with thermonuclear devices in the 1-megaton range, the cost of energy is about twice that from coal or natural gas using published prices. Still larger devices would cost little more, and multimegaton thermonuclear explosives would compete costwise with conventional sources of heat, if they can be used effectively.

TABLE 2. COMPARISON OF ENERGY COSTS FOR NUCLEAR DEVICES AND CONVENTIONAL FUELS

	Nuclear Devices					Conventional Fuels		
	10 kt	100 kt	1,000 kt	10,000 kt	100,000 kt	Coal[b]	Oil[c]	Gas[d]
Charge for Nuclear Explosive[a]	$500,000	$750,000	$1,000,000	$1,100,000	$1,200,000	--	--	--
Typical Unit Cost for Fuels	--	--	--	--	--	$6.50/ton	$2.50/bbl	$0.25/MCF
Cost per Therm[e]	$2.50	$0.38	$0.05	$0.0055	$0.0006	$0.028	$0.046	$0.028

(a) Includes charges for the device, placing it in position, making attachments, firing, and safety provisions. Does not include site preparations or construction activities.
(b) Pennsylvania.
(c) New York.
(d) Texas.
(e) 100,000 Btu; 50 per cent recovery assumed for nuclear devices, 90 per cent recovery for fuels.

It is interesting to compare the cost of heat from nuclear explosives with the cost of heat from the fissioning of fully enriched uranium, based only on the cost of the enriched uranium. The cost of heat from fully enriched uranium is nearly the same as the cost of heat from coal or natural gas, and only about half as much as that from a 1-megaton nuclear explosive. While processing costs now increase the cost of heat from enriched uranium, improvements in processing techniques and the use of lower cost fissionable materials will give energy costs below those for the nuclear explosives. Thus,

reactors appear more promising as a way of using heat from atomic energy than do nuclear explosions, at least for explosions up to 1 megaton in size.

Hence, it must be concluded that heat produced from nuclear explosions in anything except the larger sizes cannot complete economically with existing conventional processes. Costs of nuclear explosives would have to be reduced by a factor of 50 to 100 in the 10-kiloton range and by two in the megaton range to become competitive, assuming the correctness of quoted prices.

Explosive Energy Produced

Nuclear explosives provide an effective means of moving and breaking large quantities of earth and rock. Equivalent in explosive power to from 50 tons to a few million tons of conventional explosives, nuclear devices are compact, being packaged in a case from 7 to 14 feet long and 30 to 36 inches in diameter. This small size permits nuclear explosives to be placed in position more easily and at less cost than equally effective chemical explosives. Although chemical explosions of more than 500 tons have been fired, such huge blasts have been rare.

Table 3 shows the relative costs of nuclear and chemical explosives based on their heat of explosion. It is evident that nuclear devices are economically attractive. Even the cheapest of the commercial explosives costs nearly three times as much as the most expensive nuclear explosive. Comparing a megaton thermonuclear device with TNT shows that the yield per dollar is 400 times greater for the thermonuclear explosive.

However, nuclear devices are less efficient blasting materials than chemical explosives, with the result that the heat of explosion is utilized less effectively. While only 1 pound of conventional explosive is required to excavate 1 cubic yard of rock, or about 2 million cubic yards per kiloton, nuclear devices excavate from 100,000 to 300,000 cubic yards per kiloton. This fact changes the economic situation, and it is found that nuclear explosives are cheaper only for the larger explosions. The cost of the

TABLE 3. COMPARATIVE COSTS OF NUCLEAR AND CHEMICAL EXPLOSIVES

	Nuclear Devices			Ammonium Nitrate, Fertilizer Grade	40% Blasting Gelatine, 2 x 16 Cartridges	60% Blasting Gelatine, 2-1/2 x 16 Cartridges	INI
	10 kt	100 kt	1000 kt				
Charge for Nuclear Explosive	$500,000	$750,000	$1,000,000	--	--	--	--
Typical Cost of Chemical Explosives, $/100 pounds				$6.75	$18.25	$19.25	$20.00(b)
Energy in Nuclear Explosion, Btu	4×10^{10}	4×10^{11}	4×10^{12}	--	--	--	--
Btu/$(a)	8×10^{4}	5.3×10^{5}	4×10^{6}	3×10^{4}	1.1×10^{4}	1.0×10^{4}	1×10^{4}
Relative Cost of Heat of Explosion per Million Btu	$12.50	$1.88	$0.25	$34	$91	$96	$100

(a) Based on heat of explosion of 2000 Btu/pound for conventional explosives.
(b) Not being produced commercially today. Used almost solely as military explosive, with small amount added occasionally to proprietary explosives and boosters.

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explosive alone is 12 cents per cubic yard for a 100-kiloton device and 2 cents per cubic yard for a 1-megaton device, compared with 20 cents per cubic yard for conventional explosives. Larger explosions would give even cheaper blasting. Smaller nuclear explosions cost more than chemical explosions, per cubic yard excavated.

On this basis, where large explosions are required or can be tolerated, nuclear explosives are cheaper than chemical explosives.

Radiation Hazards

Radiation is a problem with nuclear explosions, although the fireball is completely suppressed and there is no flash or incendiary effect with even shallowly buried explosions. Shallow blasts, nevertheless, discharge nearly all their radioactivity into the air. As the depth increases, more of the radioactive debris is trapped in the surrounding soil, until with the deepest blasts no radiation is detectable at the surface.

Radioactivity trapped in the zone surrounding a deeply buried explosion is confined largely to a shallow layer of fused rock. This radioactivity can be transferred to ground water flowing through the site of the explosion, but is quickly absorbed by strata outside the explosion area. In general, the problem of transferring radioactivity from a deeply buried explosion to underground water supplies is not considered serious, but the problem has not yet been entirely evaluated. Far more study would be required before it could be proved that a radiation hazard did not exist for any given situation. Radioactivity trapped in the soil or in rock would pose special problems in mining applications.

Seismic Shock

Ground waves produced by underground nuclear explosions are relatively weak, although they have served effectively to increase man's knowledge of the earth's crust. Similar in some respects to an earthquake, nuclear-explosion-induced seismic disturbances die out far more rapidly than do natural earth tremors. Thus, although localized

effects are similar to those from an earthquake, the intensity and range of damaging effects from an underground nuclear explosion are appreciably less.

Possible Future Uses of Nuclear Explosives

Harbors and Canals

Because of their effectiveness in excavating, nuclear explosives have been suggested in a test known as Project Chariot for producing a harbor on the Alaskan coast at Cape Thompson, 350 miles above the Arctic Circle. A harbor in this location would facilitate exploitation of Alaska's reserves of coal and oil. It has been proposed that five nuclear devices be exploded simultaneously, three 20-kiloton explosions to provide an entrance channel, and two 200-kiloton explosions to form the main turning basin. At a scaled depth of 260 feet, most of the excavated permafrost soil would be thrown free of the craters, and from 5 to 20 per cent of the radioactivity would be released. The isolated location of the experiment would minimize problems of fall-out.

Another suggestion has been to excavate a canal across Central America, 100 miles south of the Panama Canal. As visualized, this would require the firing of 651 nuclear devices having a total yield of 42 megatons at a cost estimated at $2.1 billion. It is estimated that excavating with conventional explosives might cost $5.1 billion. There appears to be little likelihood that such a project would be undertaken.

Thermal Storage

Although thermal energy from nuclear explosives is not attractive economically at present, one test to define the technical problems more specifically is now in the planning stage. Known as Project Gnome, it proposes to detonate a 10-kiloton device 1200 feet below the surface in the Salado Formation salt beds 25 miles southeast of Carlsbad, New Mexico. Information would be obtained from such a shot on some of the engineering

problems involved in recovering useful heat from an underground explosion. Practical applications of such energy seems quite unlikely for many years to come.

Recovery of Hydrocarbons from Tar Sands

One venture has been proposed to recover oil from the Athabasca tar sands of northern Alberta. Here the explosive energy of the device would be used to produce a large quantity of crushed tar sands 1300 feet underground, with the thermal energy providing a pool of heated low-viscosity oil which could then be pumped to the surface. No cost breakdown has been reported for Project Oilsand, the main intent apparently being to explore any possible method of recovering useful products from this exceedingly large hydrocarbon deposit.

Petroleum Production

Suggestions have been made that nuclear devices detonated in an oil-bearing strata could increase the recovery of petroleum from a given reserve at lower cost than conventional methods. Too little information is available as yet to predict the action of a nuclear device in such an application. Because of the size of a nuclear device, a cased hole larger than 30 inches in diameter would be required to place the nuclear explosive in position. Although cased holes as large as 42 inches have been drilled, their cost has been high. With most of the oil reserves in the United States located between 2000 and 8000 feet below the surface, it does not appear practical at present to exploit these with nuclear explosives.

Oil shale also has been considered for testing the usefulness of a nuclear explosive. Two possibilities exist, (a) to use the nuclear explosion to crush the shale prior to mining it and transporting it to a processing plant, or (b) to use the nuclear explosion to initiate controlled combustion in the shale and to retort it in place. Economically, neither method appears promising. The feasibility of either scheme cannot be appraised at the present time.

Mining

Improvement in mining practices by the use of nuclear devices has been considered because of the favorable costs of nuclear explosives. Although the feasibility of nuclear blasting seems established, application to mining where small, controlled explosions are necessary has not been demonstrated. The need for caution against damaging irreplaceable ore bodies by large nuclear blasts should delay tests in mineral deposits until data are available on the action of nuclear devices in rock of different types.

Potable Water

Because there are many areas in the world where potable water is in short supply, nuclear explosions have been considered for supplying the heat needed for distillation processes, or for producing underground aquifers where water could be stored. Heat from nuclear explosions is too expensive for distillation except for the very large devices, particularly in view of the high thermal efficiency now being obtained by distillation plants using conventional sources of energy.

Underground storage basins produced by deeply buried nuclear explosions may have more merit, but their potentialities cannot be estimated until more data are available on the characteristics of such explosions in different types of underground structures, and on the extent of radioactive contamination.

Conclusions

The Plowshare studies are in a preliminary stage, suggested uses are speculative, and it is too early to make adequate evaluations of the ultimate uses for which nuclear explosives might be practical. Many tests would need to be made before the capabilities and the limitations of these devices can be stated.

If practical applications are demonstrated, their usefulness to other nations can be judged more accurately.

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FOOD PRESERVATION BY IONIZING RADIATION

Because individual classes of foods differ in their requirements for preservation, a number of methods have been developed over the years involving one or a combination of procedures such as dehydration, fermentation, salting, chemical treatment, canning, refrigeration, and freezing. The basic objectives in each instance are to make available supplies of food during the intervals between harvesting or slaughter, to minimize losses resulting from the action of microorganisms and insects, and to make it possible to transport foods from the area of harvest or production to areas of consumption.

In earlier years, the preservation of food was essentially related to survival. In the more sophisticated atmosphere of today's developed nations, food-preservation techniques have sought also to bring variety, peak freshness, and optimum taste and flavor in foods at reasonable cost to the consumer.

With the development of nuclear technology, isotopic materials and machine radiation sources in recent years, the possibilities of applying ionizing radiation to the preservation of foods attracted the attention of investigators in the United States and throughout the world. An early hope that irradiation might be the ultimate answer to practically all food-preservation problems was soon dispelled. Interest remained, however, in the possibility that it would serve as a useful supplementary method for counteracting spoilage losses and for preserving some foods at lower over-all costs than freezing, or without employing heat or chemicals with their attendant taste alterations.

Factors Responsible for the Spoilage of Foods

Spoilage Factors

The chief factors responsible for the spoilage of fresh foodstuffs are (1) microorganisms such as bacteria, molds, and yeasts, (2) enzymes, (3) insects, (4) sprouting, and (5) chemical reactions. Microorganisms are often responsible for the rapid spoilage

of foods. Of special concern is the growth of bacteria such as Clostridium botulinum which generate poisonous products. Enzymatic action in stored food produces changes which can adversely affect the appearance of food or its palatability. Spoilage by chemical action results from the reaction of one group of components in the food with others or with its environment, as in corrosion of the walls of metal containers or the reaction of fats with oxygen in the air to produce rancidity.

Sprouting is a naturally occurring phenomenon in stored potatoes, onions, carrots, beets, and similar root vegetables. Insect infestation is a problem of importance chiefly in stored grain. The presence of parasitic organisms such as Trichinella spiralis in pork introduces another factor which must be dealt with in food processing.

Countermeasures

To permit the storage of food for long periods of time, a method of preservation must accomplish the destruction of microorganisms and inhibition of enzymatic action. The term "sterilization" applies to methods involving essentially complete destruction of all microorganisms. Foods treated in this manner and protected from recontamination by asceptic methods of packaging and containment presumably could be stored for long periods without refrigeration. The process of "pasteurization" involves milder and less prolonged heat treatment which accomplishes the destruction of most but not all of the microorganisms. Canned foods are a product of a sterilization process, where the can and its contents are processed by steam under pressure in autoclaves. The can offers protection to the contents from recontamination and oxidation. Less severe thermal treatment as by blanching or scalding serves to inactivate enzymes.

Provision of low temperatures serves to slow down chemical action as well as the growth of microorganisms and enzymatic action. Refrigeration temperatures serve to extend the storage life of fresh and prepared foods by a matter of days. For satisfactory preservations over longer periods, a matter of months, freezing temperatures of 0 F or

below are required. A blanching or low-grade heat treatment can be used to inactivate enzymes before freezing.

Dehydration processes have long been used to preserve certain meats, fruits, and vegetables. Through the elimination of a large proportion of the water content, the dehydrated product requires less storage space and transportation costs are reduced. Processing costs are low, but the dehydrating process results in changes in texture, taste, odor, and color which reduces acceptability in many instances except for occasional or emergency use. Combinations of dehydration either before or after freezing have also been developed. The process of freeze-dehydration is said to minimize the collapse of cell walls, which occurs during ordinary dehydration, and the palatability of some foods is increased while eliminating weight and lowering transportation costs. Partial dehydration-freezing processes, as used to prepare concentrated frozen fruit juices, provides extended storage life, high palatability, and reduced weight and volume of the product during transportation and storage.

Preservation of foods by chemical treatment creates conditions which inhibit or prevent undesired actions by enzymes, microorganisms, and insects. Fumigation of grain, addition of small amounts of calcium propionate in bread to retard growth of mold, and the injection of antibiotics in chickens are examples of chemical treatment for preservation.

Control of the environment in storage areas – temperature, humidity, and atmosphere – represents another method of extending the storage life of fruits and vegetables. An example is the introduction of carbon dioxide into refrigerated storage areas containing apples.

General Effects of Ionizing Radiation

Ionizing radiation can cause the destruction of microorganisms and insects involved in food spoilage or, at lower doses, can inhibit their action. Different foods react in different ways to irradiation treatment with respect to the taste, color, texture, and general palatability of the product being treated. Radiation also furnishes a means of destroying insects in stored grain products as well as certain parasitic organisms present in meats.

Radiation can cause the deactivation of enzymes, although some types require extremely heavy doses of 10 Mrad* or more. Undesirable flavors, odors, colors, and generally low palatability are associated with radiation treatment of this magnitude. Hence, the inactivation of enzymes is best accomplished prior to irradiation, which is a "cold" process, by the conventional heat-processing method of blanching.

Radiation does not retard the chemical spoilage of food. It will, however, inhibit the sprouting of potatoes and other root vegetables.

The radiation doses required for the preservation of foods are in the following ranges:

(1) For radiosterilization, to accomplish essentially complete destruction of all organisms for long-term preservation – about 4.5 Mrad for nonacid foods of low salt content. (1)**

(2) For radiopasteurization, to accomplish partial destruction of microorganisms; results vary with types of food, storage conditions, and objectives of treatment – commonly of the order of 200,000 rads but up to about 800,000 rads.

(3) For destruction of insects – about 25,000 rads. (2)

* A rad is the unit signifying the energy absorbed from ionizing radiation by a unit mass of irradiated material, and is equal to 100 ergs per gram. A Mrad is one million rads. In terms of engineering units, 1 rad is equivalent to 1.28×10^{-6} watt-hours per pound.

** References for this section are given on page 122.

(4) For inhibiting the sprouting of potatoes, onions, etc. –

4,000 to 10,000 rads.[3,4]

In accomplishing preservation objectives by treatment of foods with ionizing radiation, some undesirable side effects become evident, particularly at the higher radiation dosages. In this respect, the general palatability and individual acceptance of most radiosterilized foods has, to date, been found to be low in comparison with fresh and commercially processed foods. At substantially less than sterilization levels, however, a number of foods are quite acceptable as regards taste and palatability. The nutritive value of irradiated foods apparently undergoes little, if any, change, although there is a specific effect on some of the fat-soluble vitamins present at sterilization doses.

High energy radiation (10 Mev and above) can induce radioactivity in foods. This applies to both gamma and electron radiation. However, this effect is believed to be avoided by using lower but still useful levels, although complete absence of induced radioactivity and characterisation of the useful energy levels still require conclusive proof.

Radiation Sources

For irradiation of food, the results obtained depend upon the dose rather than the specific type of radiation, and X-ray, gamma, and high-energy electron radiation are suitable. Aside from availability and economic considerations, each has certain practical advantages; for example, gamma rays give deeper penetration but cannot be focussed or collimated, whereas unidirectional electron beams may be split and directed to both the top and bottom of the food package to be irradiated. Selection of a source for commercial irradiation would involve consideration of numerous factors including required dose rate, load factor, throughput, convenience, safety, and most important, costs.

The potentially useful sources of ionizing radiations have been discussed earlier in this report. For gamma sources, cobalt-60, cesium-137, fission products, or a reactor irradiation loop system using a material such as an indium salt have received most attention for food-preservation systems. Of the various particle accelerators, the Van de Graff machines, resonant transformers, and linear accelerators are the principal ones available for commercial use.

Costs of the effective energy produced by these sources is a major obstacle in the development of food-preservation processes. Production costs of radiation energy from machine and nuclide sources have been estimated[5,6] to range from $1 to $10 per kwhr. With conventional energy for processing foods available in the range of at most a few cents per kwhr for electric power and the equivalent of a few mills per kwhr for process steam, radiation is at an initial cost disadvantage even though only 1 to 10 per cent as much radiation energy as heat energy is required for radiopasteurization or radiosterilization. With respect to the possibilities of lowered radiation production costs for the future, it has been estimated that costs for applications on a megawatt scale might reach values in the neighborhood of 10 cents per kwhr[5] for large-scale accelerators or for gamma radiation generated in a reactor core. No comparable reductions in the cost of nuclide radiation are foreseen. Such projections appear highly speculative and the capacities involved are far beyond those foreseen for food-preservation facilities.

Because agricultural activities are seasonal and the areas of production and harvest of many foods are widely scattered geographically, and because of the high cost of transporting bulk food items any substantial distance to a central processing location, the use of large central processing stations where low-cost radiation facilities approaching the megawatt range might be utilized is inherently impracticable.

Present Status of Irradiation Preservation of Foods

The objective of complete sterilization of foods is to produce a wholesome and palatable product capable of being stored without refrigeration for extended periods of time. High radiation doses are required since the Cl. botulinum organism must be destroyed. Chief interest in radiosterilization resides in the military services where the problems of providing appetizing food under battle or emergency conditions is of paramount consideration. Required are completely sterile foods capable of being stored without refrigeration, and of high nutritional value, variety, and appetizing appearance and palatability for reasons of morale, preferably items that are already cooked and ready to eat. Uncooked foods for rear stations which require cooking but no refrigeration are also of interest. The foods of primary interest are meats.

Radiopasteurization employing lower than sterilization doses produces fewer adverse sensory changes in food products and has potential usefulness in prolonging the keeping qualities of fresh and refrigerated food items. By thus serving to enhance keeping qualities, food processed at substerilization radiation doses potentially might reach markets more remote from production or harvest areas and permit more produce to reach the consumer during peak freshness and palatability. Commercial interest is chiefly in this type of treatment, as is military interest under peacetime conditions.

The present status of food preservation by ionizing radiation is discussed by food classes in the following paragraphs.

Meats

The radiation processing of meat has received extensive investigation. To date, the one meat showing favorable results at sterilization doses is pork. Of particular interest to the military services is the demonstration that roast pork that is subsequently

radiosterilized is superior in palatability to presently available canned pork products. Tests with beef have been largely unsuccessful because of the development of off-flavors. One of the prime objectives of the Army Quartermaster Corps program is to determine the reasons for the low palatability and to find means of overcoming it, since beef is a major and desirable dietary item. Partly because of the necessity for low-level heat treatment to inactivate enzymes before sterilization, radiosterilized fresh meats have the appearance of boiled or canned meat rather than having the color and general appearance of fresh meat. Satisfactory results have been reported by the Army for the radiation processing of bacon at sterilization doses.

Problems associated with the radiopasteurization of meats are less severe with respect to the production of off-flavors, but problems of commercial acceptability remain. It has been demonstrated that moderate radiation doses of from 100,000 to 200,000 rads can extend the shelf life of fresh beef at refrigeration temperatures (35 F) to 5 or 6 weeks from the usual 5 days. However, there remains the problem of consumer acceptability because of the necessity for a blanching treatment before radiation treatment, which circumvents undue enzyme activity, and the problem of liquid accumulation in prepackaged cuts of beef, in particular. Again, the blanching process results in unnatural colors for the treated beef. Cooked beef irradiated in the absence of oxygen assumes an unnatural pink color.

When lamb and mutton are irradiated at substerilization doses, the meat becomes dehydrated, the fat becomes chalky, and, again, unnatural changes in color occur.

Ground meats such as fresh pork sausage and hamburger have a relatively short shelf life under refrigeration, and radiopasteurization might be thought to offer distinctly improved keeping qualities. However, among others, the problem here is one of scale of processing; ground meats are usually prepared from scrap meats at the local level, whereas irradiation at economic volumes of production would require central

processing and distribution facilities. The problems of color change by blanching and liquid accumulation within the package are the same as for solid cuts.

Specialty cooked items containing meat portions, as in "frozen dinners" might offer a potential use for radiopasteurization. The principal potential advantage would be that the finished product could be transported and stored at lower cost under refrigeration instead of being frozen. A refrigerated item could also be heated and served in less time than is required for frozen foods of the same type.

Competitive processes for preserving meats are by canning and freezing. Costs of canning meat are in the range of 0.8 to 5 cents per pound; costs of freezing are in the area of 2 to 3.5 cents per pound. (7) Table 1 shows comparative costs of canning and freezing meat, and estimated costs for irradiation under certain assumed conditions. (8) Under the conditions of comparison, it will be noted that:

(1) Radiosterilization (at 3 Mrad) is more expensive than canning, particularly for the cesium-137 source.

(2) Radiopasteurization by either the electron accelerator or cesium-137 source is in the range of freezing costs.

(3) Irradiation using the nuclide source is more expensive than use of an electron accelerator.

Poultry

Results of irradiation tests with poultry have been quite successful. At sterilizing doses, good palatability results, with a minimum of changes in appearance, taste, and odor. Radiopasteurization has also been successful, and the shelf life of chicken can be extended to a month or more under refrigerated storage as compared with about 10 days for the untreated product. Acceptable taste and odor are retained by the irradiated and refrigerated chicken. Acceptance of radiopasteurization is likely to be delayed, however, for two reasons: (1) the storage life of fresh chicken under refrigeration is

TABLE 1. COMPARATIVE COSTS OF CANNING, FREEZING, AND IRRADIATING MEAT[a]

Cost Elements	Irradiating Costs[b], cents/lb				Thermal[c] Costs, cents/lb (Standard Retorts)	Freezing[c] Costs, cents/lb (Plate Freezers)
	Electron Accelerator		Cesium 137			
	10^5 rad	3 M rad	10^5 rad	3 M rad		
Raw material						
Preparation for processing	Same for all processes					
Processing	0.33	0.87	0.62	4.89	0.16	0.32
Packaging	2.19	2.48	2.19	2.48	2.48	2.19
Transportation[d]	1.95	1.50	1.95	1.50	1.50	2.10
Storage[e]	0.39	0.12	0.39	0.12	0.12	0.42
Total	4.86	4.97	5.15	8.99	4.26	5.03

(a) Production basis. In all cases, 43,200,000 lb are produced per year. Thermal and freezing costs are based on an 8-hour day, 300 days per year. Irradiation costs are based on 9000 lb processed per hour, 16 hours per day, 300 days per year.

(b) The costs of radiation processing are based on the following costs per kilowatt-hour emitted from the source.

a. 2.26 kilowatt electron accelerator (10^5 rad dose): $11.40.
b. 68 kilowatt electron accelerator (3 M rad dose): $ 0.95.
c. 2.26 kilowatt cesium 137 source (10^5 rad dose): $19.15.
d. 68 kilowatt cesium 137 source (3 M rad dose): $ 6.30.

Source power levels are established by assuming a 50% absorption efficiency in all cases.

In addition to these costs, in all cases a cost of 0.14 cent per pound (separately estimated) was added to cover nonsource direct labor and overhead and amortization of the building and conveyor system.

(c) Thermal and freezing costs were obtained from producers in the field.

(d) Cost of transportation is from Chicago to San Francisco.

(e) Storage costs are estimated for private facilities.

Source: Reference 5, p 227.

becoming a minimal problem because of constantly improved sanitation and distributing practices, and (2) treatment by antibiotics, a measure already approved by the Federal Food and Drug Administration, serves to extend the storage life of chicken at a low cost of about 0.5 cent per pound.

Seafood

Fresh seafood products are extremely perishable. Although refrigeration has served to extend the storage life of these products, substantially increased consumption should be possible if areas remote from the seacoast could be served adequately. Radiopasteurization has been found to extend the refrigerated shelf life of a number of seafoods by a factor of four. Tests have shown that such items as cod, halibut, ocean perch, shrimp, crabmeat, oysters, and lobster retain characteristics believed to be acceptable to the consumer. Palatability after irradiation at sterilization doses is more questionable, although acceptable results have been reported for oysters, shrimp, codfish cakes, tuna and others.[9] A competitive process for most seafood products is freezing, which results in highly acceptable and palatable products which can be distributed to distant markets.

Vegetables

Little commercial interest exists in the radiosterilization treatment of vegetables. Changes in characteristics commonly occur. At substerilization levels of treatment, fair results have been obtained with vegetables such as carrots and asparagus, but it is not possible to generalize. For most vegetables, factors of texture and taste associated with garden-fresh produce are of extreme importance. Provided a high degree of palatability can be demonstrated, the interest in vegetable irradiation would be to reduce spoilage losses of fresh produce at costs competitive with those for freezing, and perhaps to increase the time vegetables can be held at processing plants after harvesting to

add to the time available for conventional processing. Again, however, the logistics of gathering produce for an irradiation installation large enough to be economic under seasonal conditions appear unfavorable.

Fruits

Some varieties of cherries, grapes, strawberries, blueberries, peaches, and citrus fruits have shown fair to good product acceptability after irradiation at low pasteurization doses to inhibit stem rot and formation of surface molds. Since irradiation at low doses has been shown to kill the larva of various fruit flies, it is also possible that more extensive marketing of tropical fruits such as papayas might be feasible.

Until more facts are known regarding the economic comparison of radiopasteurization plus refrigeration with freezing techniques, it is impossible to estimate the commercial feasibility of irradiation methods. Seasonal harvesting and logistic considerations again present formidable economic problems.

Inhibition of Sprouting

Small doses of radiation of the order of 10,000 rads have been shown to extend the storage life of potatoes, onions, sweet potatoes, beets, and carrots by preventing sprouting. No significant changes in flavor accompany the irradiation. One drawback experienced with potatoes has been the increased susceptibility to bruising and the development of black rot.

Although technically feasible, the economics of treating by radiation to prevent sprouting are questionable. Treatment costs must be low, perhaps of the order of a fraction of a mill per pound, and methods of chemical treatment and controlled ambient atmospheres may show economic superiority since substantial capital costs are not involved.

Grain Disinfestation

Low radiation doses in the range of 10,000 to 30,000 rads have been found sufficient to disinfest grain, and the operation appears to be technically feasible. Interest in this application stems from the fact that losses of grain due to the action of insects during storage may be as much as a quarter of a billion dollars annually. Losses are understandably higher in farm storage structures than in the large, central storage silos of commercial mills. Losses have been estimated at 10 per cent for the former as compared with 1 to 2 per cent for mill storage. (10)

The economics of treating grain by radiation have not been fully developed, but appear unfavorable. The accepted practice for grain disinfestation is chemical fumigation with costs in the range of from 0. 2 and 0. 6 cent per bushel of grain. Costs of irradiation on a commercial basis are not known, but estimates have been given in the range of 0. 35 to 2. 3 cents per bushel for electron generators. (11)

Again, as is true for other proposed irradiation systems involving agricultural products, a major difficulty lies in the logistics of the situation. For grain, the problem is that highest losses occur in storage facilities at widely separated locations, indicating the need for small-scale dispersed units or mobile ones whose operating costs are higher. Any irradiating system in a fixed location except, perhaps, for large mills would have an extremely low load factor, which again is allied with high-cost operation. Large-scale storage units at central mills would be a more favorable situation for an irradiation facility, but in this instance the losses are lower and chemical fumigation procedures appear to be adequate.

Additional questions as yet unanswered involve the problem of reinfestation and the probable need for multiple irradiation of the same stored grain, since grain is often stored for 2 or 3 years. The sum total of the accumulated dosages may result in changes adversely affecting either the flavor or quality of the final baked product made from the milled grain. Irradiation doses of the order of 10^5 rads are known to interfere

with germination and growth of seed wheat, and some damage in germinating characteristics is noticeable at lower doses.

Milk

Irradiation of milk and other dairy products is accompanied by pronounced and undesirable changes in flavor and color. The problems of milk irradiation include formation of a tallowy off-flavor, development of a brown color and a carmelization flavor on storage, and a tendency to flocculate. Off-flavors can be reduced to a satisfactory level by irradiating while boiling the milk under a vacuum, and flocculation can be reduced by the addition of tripolyphosphate or certain metal ions to the milk before irradiation. However, the over-all problem involved in the irradiation of milk, including browning and flavor changes, has not been completely resolved. With availability of fresh pasteurized milk throughout most areas of this country through developments by the dairy industry in processing and transporting milk, and the availability of acceptable grades of dry milk solids, there appears to be little, if any, incentive for commercial irradiation in this area.

Wholesomeness of Irradiated Foods

Legal Aspects

Whatever the technical feasibility and economics of processes for the irradiation of foods for human consumption, the factor of wholesomeness is of overriding significance. The term "wholesomeness" covers both the nutritive quality and factors of potential toxicity of the irradiated food products. Under the 1958 Food Additive Amendment of Federal Public Law No. 85-929, the burden of proof of the safety of any food process or chemical additive is placed directly upon the processor or manufacturer. The law is administered under the Federal Food and Drug Administration for the

protection of the consumer, and offers a positive approach to the problem of control of food toxicity and potential hazards.

Because of the considerable interest of the military services in irradiated foods, a comprehensive program for evaluating the wholesomeness of irradiated foods has been conducted under the auspices of the Department of the Defense, particularly through the Office of the Surgeon General, U. S. Army, where a test program has been in effect since 1953. Within this program, in addition to Army facilities, over 30 different research groups have participated in making the studies, including university scientists, research foundations, and Government laboratories. Although commercial food-processing companies have been interested in the results and have cooperated to the extent possible, the necessarily large expenditures in time and money has prevented their assuming more than nominal interest at this stage of development of food-irradiation processes. The Army wholesomeness assay program has been carried on with the full cooperation of the Food and Drug Administration, particularly in regard to research procedures and techniques. The responsibility for proving the wholesomeness of irradiated foods is complicated by the necessity of assaying each individual food, or a number of each class and type, at both sterilization doses and below. Until such time as the wholesomeness of irradiated foods is proven beyond dispute, there can be no commercialization of the process for either the military or civilian market.

Nutritive Value

From tests made to date, principally with animals, irradiative treatment appears to have little effect upon the nutritive value of the carbohydrates, fats, and proteins present in foods. Small differences in biological value, digestibility, or energy content have been observed in some irradiated foods, but not to a degree sufficient to affect the nutritional value of mixed diets.[12] This result applies as well to foods that have been stored for some time after irradiation.

Irradiation does, however, have a marked effect on the vitamin content of foods. The water-soluble vitamins are sensitive to ionizing radiation in varying degrees; niacin is the least sensitive and thiamine the most sensitive. The destructive effect is greater for vitamins in aqueous solution than for those occurring in foods, and the effect on a given vitamin varies with different foods. The extent of destruction by irradiation at sterilization doses is similar to the losses of vitamins produced by heat processing, but the destructive effect on vitamins might be compounded when irradiated foods are subsequently cooked. For diets employing irradiated foods at sterilization doses, supplementary water-soluble vitamins probably would be required. However, it is generally believed that a mixed diet of irradiated and raw natural foods would introduce an adequate amount of the vitamins under conditions of the average consumer household. This necessity would not, however, enhance the acceptance by the housewife of irradiated foods.

The fat-soluble vitamins, A, E, and K, are more sensitive to ionizing radiation than are the water-soluble ones and are easily destroyed. Problems of impairment of reproductive capacity and of bleeding in animals have resulted from the feeding of irradiated foods. The addition of supplementary additions of Vitamins E and K overcomes both problems, the latter being of a nutritional nature influencing the clotting time of the blood. Extension of the bleeding tendencies observed with rats, which have been fed irradiated meats, to humans under the same conditions is not readily made since the Vitamin K requirements of humans or the significance of the intestinal micropopulation in satisfying Vitamin K needs are not known. (13) Based on work done to date, there are no indications from animal tests that growth, life span, lactation, or reproductive capacity have been changed in any significant manner by the consumption of irradiated foods provided adequate amounts of supplementary vitamins have been added to the diet. (12,13)

Toxicity

The problems of bleeding and other effects observed in animals, as mentioned briefly in the foregoing paragraph, might properly have been discussed under this heading. However, these effects are probably classified more properly as nutritional deficiencies rather than as effects induced by the synthesis of toxic substances during or following the irradiation process. With one possible exception, the phenomenon of rupture of the auricle of the heart observed in mice[14], the consensus appears to be that animal tests have shown few, if any, indication of toxicity of irradiated foods[12,13,15,16], nor have the limited tests with humans that have been made to date. Evidence on the heart-rupture problem is somewhat conflicting, but additional tests should serve to delineate the problem as one of direct toxicity of irradiated foods or as an associated nutritional problem.

Induced Radiation

Although either gamma or electron-beam radiation having energies of the order of 10 Mev and above can induce radioactivity and produce radioactive isotopes from elements in foods, experimental evidence indicates that gamma sources of relatively low energy such as cobalt-60 and cesium-137, or X-rays and electron beams of similar energy levels, do not induce activity in foods in amounts that can be detected. The hazard of induced radiation from either gamma or electron sources having energies below 2. 2 Mev is minute or nonexistent. [17] The detection and evaluation of the induced radioactive effect and assay of the biological hazard from minute amounts of radiation is a difficult task. However, the cumulative effect of the intake of even these minute amounts of degradation products or of possible radioactivated elements must be evaluated by biological methods to demonstrate adequately that the effect on man is infinitesimal and beyond hazard. Quite aside from legal and regulatory aspects, it is highly

improbable that the consumer will ever accept anything but proof of the complete absence of any conceivable adverse effect from irradiated foods.

Current Research Programs

Although a considerable amount of research effort has been carried on by universities, private research organizations, and industry, the major effort in the field of preservation of food by ionizing radiation has been sponsored by the Department of Defense. Lest the effort maintained by the commercial food processors be minimized, it should be pointed out that a recent survey(18) found that 14 food companies visited during the study had carried radiation research at a total annual rate of about $1 million for several years prior to 1959. Expenditures during 1959 were estimated to be much lower, since several companies had stopped work on this area and most of the others had curtailed research pending the outcome of the Quartermaster studies and the tests at the proposed pilot plant at Stockton, California.

In addition to the extensive research program carried on by the Office of the Surgeon General, U. S. Army, on the wholesomeness testing of irradiated foods, and the general research program of the Quartermaster Corps, the proposed Army Food Irradiation Center to be constructed at Sharpe General Depot was of major interest. This was to be a pilot-plant facility capable of irradiating and processing foodstuff at a rate of about 3000 pounds per hour. Irradiation sources planned for the facility were a 2.2-megacurie cobalt-60 source and a 24-Mev linear accelerator. The program planned for this installation was of a magnitude sufficient to determine technical operating problems and process economics, and to permit large-scale feeding tests to determine the acceptability and adequacy of irradiated foods in human diets.

Work on construction of the two irradiation sources was under way when, on October 22, 1959, the Department of Army announced that it had indefinitely suspended

its plans to construct and operate the irradiation center. Given as reasons by the Army for the abrupt termination of plans for the pilot-plant installation were (1) the venture was premature because there remained certain unresolved questions concerning the results of animal feeding tests with irradiated food, and (2) there yet was no real economic justification for constructing the large-scale irradiation facilities since further and more detailed economic studies were deemed necessary to show that irradiation food processing techniques had an economic and logistic advantage for military use over conventional freezing and dehydrating processes. A further decision was made to readjust the Army program to emphasize further laboratory research which would be concerned wholly with the radiosterilization of selected foods of military interest.

There has not been complete agreement by industry and other Departments of the Federal Government that the abrupt abandonment of plans for an irradiation food-preservation center to permit more detailed study of associated technical and economic studies was justified on a broad national basis. Accordingly, an Interdepartment Committee on Radiation Preservation of Food was established at a meeting on November 24, 1959, to consider the advisability of proceeding with a complementary program concerned chiefly with potential civilian interests in the preservation of food by ionizing radiation. An ad hoc committee was appointed to review the situation and to make recommendations for a research and development program. Members of the Committee were representatives from the Atomic Energy Commission, the Departments of Commerce, Interior, Agriculture, and Health, Education and Welfare, Small Business Administration, Quartermaster Food and Container Institute, and Office of the Surgeon General. A preliminary report of this ad hoc panel was tendered to the Interdepartmental Committee in January, 1960. At a meeting of the Committee in February, an augmented series of recommendations for a national civilian radiation processed foods program was adopted. The report was referred to the several Departments and Agencies for action.

The United States has been the leader in research on the radiation processing of foods. Other countries, however, have shown considerable interest in the program, and some, as facilities become available, have initiated programs of studies of their own. The international interest in radiation processing was evident at the International Conference on The Preservation of Foods by Ionizing Radiations which was held in Cambridge, Massachusetts, July 27-30, 1959. Delegates from 22 nations throughout the world presented papers on radiation-processing activities in their countries and participated in discussions outlining their needs and potential applications for specific food products.

Studies on the radiation preservation of foods were reported to be under way in England, Canada, Australia, Poland, Germany, France, and Japan. Studies are also known to be in progress in Russia. Other countries reporting organizational plans for specific studies included India, Brazil, Portugal, South Africa, and Argentina. Obviously, however, the smaller and less developed countries, for whom the needs for improved food-preservation and distribution methods may be most pressing, look to the initiative, guidance, and development of irradiation methods from the United States and others of the more industrially advanced nations.

Economics and Over-All Incentives for Commercialization in the United States

Based on work performed to date, it is evident that a number of problems must be solved before food irradiation can be adjudged economic in comparison with conventional preservation methods, completely safe with respect to the potential toxicity of the irradiated product, and, most important, acceptable to the consuming public in terms of cost, palatability, and general acceptance.

Under present conditions, the disinfestation of grain appears to hold little attraction for commercial millers. Chemical methods of disinfestation accomplish the same purpose at the same or lower costs than presently estimated for irradiation.

There is also doubt that irradiative treatment to prevent the sprouting of potatoes or some root crops will give results that are economically superior to other methods such as chemical treatment and storage in controlled ambient atmospheres. Again, the logistics of the situation and the load factor are unfavorable for achieving low irradiation costs.

Because of changes in the sensory characteristics of fruits and vegetables, the radiosterilization of these food items appears now to offer little promise for commercialization. Radiopasteurization appears to offer some promise for treating fruits and vegetables, but the economics and the potential advantages of irradiation in bettering the preservation of the ripe, fresh taste and flavor as compared with quick freezing processes has not yet been demonstrated.

The possibilities of radiosterilizing chicken and some fresh and cooked meats such as pork have been demonstrated, but the economics and consumer acceptance are not known. It is unlikely that radiosterilization of meat will reach the commercialization stage, although there is potential application for military purposes provided palatability, wholesomeness, and logistic economics can be demonstrated conclusively. Methods of treatment and storage of fresh poultry are far enough advanced at present that commercialization of irradiation treatment of any kind is extremely unlikely. Radiopasteurization of fresh meat, assuming that taste, color, and odor changes can be controlled satisfactorily, must compete directly with freezing. The comparative economics of the two processes will finally be the determining factor, together with the taste preferences of the consumer.

As illustrated by the estimated cost data for meat shown in Table 1, the direct processing cost is small relative to the total sales cost at the market. For this reason, no move toward commercialization will be made until it is shown definitely that there is an economic advantage, that the taste, texture and odor of the product is equal or superior to the product of a competitive process, and that the product is acceptable to the consumer without prejudice.

The consumer will be the final judge of radiation-preserved food products, once such foods have been given the stamp of approval by the Federal Food and Drug Administration. His acceptance of these foods will be based largely on quality and cost, assuming that his fear of anything concerned with radiation can be allayed by an educational program of some persuasiveness. However, improvement in quality might not result or might not be enough to be detected by the majority of consumers. There remains then, as incentives, the lengthening of the period during which fresh or fresh-like products reach the market, the extension of markets for fresh or fresh-like products to areas not previously reached, and the reduction of spoilage losses. All of these are potential advantages for radiopasteurized foods. These potential advantages are directed more particularly to the commercial area of interest, and over-all economics will dictate the action of the commercial groups concerned.

At this stage, it may be concluded that the interest in irradiation treatment by the food industry is marginal, that an incentive for profit which would merit their own financial effort for development on the scale required is lacking, and that the major research and development effort, if it is to be done, must be spearheaded and financed by the Government. This certainly is not a favorable atmosphere for any early commercialisation efforts, but in view of the amount of work done so far it seems logical that the investigative effort should be continued to modify flavor changes, to prove the wholesomeness of irradiated products, and to reveal a clearer picture of the economic factors.

Applicability of Radiation Preservation of Food to the Economies of Foreign Countries

The outlook for commercialization of radiation preservation of food in countries having developed economies, Great Britain and European nations, for example, may be expected more or less to parallel developments in this country. Whatever may eventually be shown to be economic and practicable in one nation of mature economy might be expected to be applicable in another, since the food marketing systems are similar. The type of research and development program discussed above would demonstrate feasibility and utility for such countries as well as it would for the United States.

The requirements for the establishment of radiation-based food-preservation programs are such that they are less practical for the underdeveloped nations even though their needs for improved methods of production, preservation, and distribution of essential foods are greater than for the more developed nations. The problems of spoilage and losses in these nations are more critical, but improvements are costly and are to be developed only gradually. In considering the applicability of radiation preservation to undeveloped nations, it is even more apparent that its broad role is one of a potential supplementary method of food processing rather than as a complete answer in itself.

In the 1956 report of the McKinney Panel to the Joint Congressional Committee on Atomic Energy, the following statement with regard to the radiation preservation of food was made:

"The food radiation preservation technique appears most readily useful in a mature industrial economy, because of the requirements for continuous mechanized processing and packaging. It will not reduce the over-all need for such elements of a modern industrial society as rapid transportation systems, efficient distribution of goods, and adequate refrigeration capabilities from food processors on through to the Nation's homes.

Radiation preservation of food will not, in itself, therefore, revolutionize the food portion of the living standards of underindustrialized nations."

This statement of the problem holds true today as well.

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AGRICULTURAL APPLICATIONS OF ATOMIC ENERGY

With the population of the world increasing at a rate equivalent to the formation of a new France every year, it follows that continual attention must be given to an at-least-equal rate of increase in food, fiber, and agricultural raw materials. These so-called renewable natural resources are the key to the postponement of the day of reckoning with the Malthusian principle. Throughout most of the world poverty is general. An example of its effect on nutrition was found in Upper Nubia where extremely low income drove the population from a diet of various cereals to corn. As one result, there was a 70 per cent incidence of pellagra in some villages. An illustration of the near hopelessness of achieving optimum diets in some countries under present conditions is given in Table 1[1]*.

TABLE 1. NUMBER OF HOURS' WORK REQUIRED FOR AVERAGE FACTORY WORKERS TO EARN THE COST (AT RETAIL PRICES IN 1953) OF THREE REPRESENTATIVE DIETS FOR ONE PERSON FOR ONE DAY

Calorie Value of Diet:	Diet A 2,100	Diet B 2,500	Diet C 3,000
Grams of Animal Protein:	10-12	15-20	40-45
Country	Hours of Work		
India	2.1	2.9	4.5
Japan	1.8	2.3	3.8
Italy	1.1	1.5	3.2
Mexico	0.6	0.8	1.4
Sweden	0.4	0.6	0.9
Denmark	0.3	0.4	0.7
Canada	0.2	0.3	0.5
United States	0.2	0.2	0.4

It will be noted that a single factory worker could not feed a family of four on a 2,500 calorie-per-day diet in India, even assuming a 10-hour working day. In Italy

*References for this section are given on page 164.

the worker would have only 2 hours' income from an 8-hour working day left for needs other than food. The desirability of a greater per capita food production in such countries is clear. It can be an especially dramatic as well as humanitarian contribution of the United States to the well being of the world to help others help themselves in improving such matters.

An inadequate protein supply is the most general type of food-quality deficiency among the world's peoples. Its most dramatic effect perhaps is shown among the young children of Middle Africa just south of the Sahara. The disease is known as Kwashiorkor. It may be translated as "displaced child" or "deprived child", which refers to the fact that children of this area almost universally acquire the disease upon weaning, occurring generally at the birth of the next child. The food available after weaning consists of starchy vegetables such as cassava, plantains, yams, and corn. The death rate from Kwashiorkor is in the neighborhood of 50 per cent. It can be reduced to practically zero by feeding dried skim milk. It would appear highly desirable for purposes of making the Central African countries self-sufficient in protein sources, and to add nitrogen to the soil as a bonus, to determine whether plant foods such as the pulses would serve as well as the necessarily imported milk product. If so, the development of hybrid varieties with the aid of radiation-induced genetic changes could well improve the child-survival rate in those countries. Pertinent to this is the following quotation from "Man and Hunger"(2).

"But in many regions it is not at present possible to produce enough milk for child feeding and the milk that is available is too expensive for most families to buy. In these areas other palatable and easily digestible protein-rich foods must be used as substitutes for milk in child feeding. It is generally desirable that they should be compounded of foods which are, or can be, grown within the country where they will be used.

"For example, an emulsion of soybean, often erroneously called soybean milk, is a partial substitute for animal milk. It has been known and used by the Chinese for many centuries."

Quite recently, news date-lined Guatemala, March 2, 1960, tells of an infant-food supplement named Incaparina for the Institute of Nutrition for Central America and Panama. It consists of corn flour, sorghum, cottonseed, brewer's yeast, and Vitamin A. Tasting like corn, it is a palatable food to Central American infants. Costing one-fifth as much as milk, it is an economic possibility to the dollar-a-day laborer. Furthermore, it may be a safer food than milk currently is in most parts of Central America.

The Food and Agriculture Organization (FAO) of the United Nations has gathered a great deal of information leading it to the conclusion that perhaps half the world is hungry. Failing to concur in this belief is M. K. Bennett[3] who doubts that the FAO data give adequate evidence of a persisting calorie shortage during the peacetime years of 1934-38. It appears, however, that not only the FAO but also individual students of world-wide human nutrition are convinced that the populations of many areas need a more adequate diet both in quantity and quality. Lord Boyd-Orr, first Director of FAO, stated in 1950, for example, "A lifetime of actual hunger is the lot of at least two-thirds of mankind". Table 2 gives a picture of the estimated food consumptions of several regions of the world and the FAO targets.

In addition to the need for more and better food, especially in the underdeveloped countries of the world, an increased self-sufficiency in food production is badly needed. Annual per capita incomes of $54 in India, less than $50 in Jordan, and $55 in Bolivia, permit little in the way of imports of food or, for that matter, of anything else.

TABLE 2. FOOD CALORIE SUPPLIES(4)

Country	Calories/ Head/Day, Actual, 1952	Calories/ Head/Day, FAO Target, 1960
Far East		
South Asia	1770	2050
East Asia	2000	2250
North-East Asia	2100	2210
Pacific Islands and Malaya Peninsula	1900	2130
Near East	2180	2370
Africa		
Northern Africa	1920	2290
Central and Tropical Africa	2080	2260
Southern Africa	2420	2470
Latin America		
River Plate Countries	3090	3090
Rest of Latin America	2250	2490
Europe		
Western Europe	2950	3020
Northern Europe	3120	3150
Southern Europe	2350	2690
Eastern Europe	2600	2700
Germany and Austria	2600	2710
North America and Oceania	3130	3110
USSR	3010	3060

Basic Agricultural Research

In many ways atomic energy can assist agriculture; specific examples will be given to serve as a guide in considering a modified program of future international cooperation in matters of atomic energy.

First, it should be pointed out that, as in many other fields of research, basic mechanisms have been studied partly to explain, out of curiosity, what has been observed before, and partly to provide a generalized basis for research programs in the future. Such research is extremely valuable, but usually it does not provide immediate or near-immediate benefits which can be expressed in terms of money or in terms of lives saved.

In agriculture especially, such research is largely done with the aid of Government funds. For the purposes of this study, such research involving the use of radioisotopes and radiation does not need to be considered as a special part of the international cooperation program because the results will become known world wide through publication. Naturally, this should continue. A few examples of the many thousands of such basic studies are as follows:

(1) A study of the process of photosynthesis using C^{14}. O^{18}, later converted to radioactive F^{18} by proton bombardment, has also been used.

(2) The discovery for the first time in plants of sulfolipids, using in the research S^{35}, p^{32}, and C^{14}.

(3) Tracing the translocation process in plants with the aid of radioisotopes.

(4) A study of the iodine-utilization mechanism in (a) ruminants and (b) poultry.

Applied Agricultural Research

Radiation has demonstrated its ability to solve a number of practical problems of agriculture in the United States. The solutions of the problems have been highly advantageous to Americans because they have contributed to improved health and greater prosperity. It is logical to conclude that an expanded and accelerated program of atomic-energy research would benefit other nations of the world. Special attention would need to be given to the agricultural problems characteristic of each such nation and every effort would need be made to translate the results into procedures which can benefit the people most and soonest. In the course of such a program, the substantial background of information derived from the basic research programs of the past and current years would be used to the utmost. Following, described in some specific terms, are subjects which might well form the foundation of agricultural atomic-energy programs of international cooperation.

Mutagenic Effects of Radiation and Development of New Plant Varieties

For many years there has been an enormous effort in the agricultural sciences to produce new varieties of economically important plants, with several objectives in mind. First can be mentioned, and then forgotten for the purposes of this report, the production of sturdier and more floriferous decorative plants for the home garden. Many of these have been produced by selection or hybridization. There have been an adequate number of sports or seedlings to give most of the stock for such developments. More recently, advantage has been taken of the chromosome-doubling influences of colchicine, which, however, should not be thought of as producing mutations.

In a very preliminary stage, however, is research on certain chemical compounds which exhibit mutagenic effects. One of these compounds, which usually contain seven-membered rings, is para-acetamidotropolone. Wada[5] has described a number of

experiments with Tradescantia reflexa and Ustilago maydis. Concentrations were from 5×10^{-6} molar to 5×10^{-5} molar. It is believed that commercial use of this method of inducing mutations remains some distance in the future.

Among the plants grown for the purpose of producing food, fiber, and industrial raw materials, such as oils, the production of new plant varieties has been undertaken with several objectives, including the following:

(1) Drought resistance

(2) Rapid growth to maturity

(3) Increased production of the desired portion of the plant

(4) Disease resistance

(5) Insect resistance

(6) Increased low- or high-temperature tolerance

(7) Improved growth habit

(8) Self fertility.

In many cases the ability to select stock for hybridization out-strips the plant material available for the purpose. Since it has been found that radiation will increase the rate of production of mutations, this situation has been alleviated somewhat. The irradiation of a cell will cause an essentially random breakage of chromosomes with the subsequent pairing in such a way as to produce, in many cases, a new genotype. By observing which of these produce some of the above-enumerated characteristics that may be useful for breeding into a new, potentially desirable hybrid, one can ignore the numerous lethal mutations and others which, although not lethal, have characteristics which are not attractive.

A bush navy bean carrying the name "Sanilac" has out-produced its parent variety by about 30 per cent and, in addition, requires fewer days to reach the harvesting stage. It is especially difficult to incorporate new germ plasm into the peanut plant because it has a rather low spontaneous natural mutation rate. Furthermore, being self-pollinated

it is not subject to natural crossing. W. C. Gregory[6], working with Arachis hypogaea, has produced abundant mutations by the use of radiation, and these have led to at least one improved peanut variety which is ready for commercial use. Such attributes are valuable in the United States; they can also be valuable in other countries by yielding more of such food production on a given acreage and requiring fewer days of labor on the part of the farmer while occupying the arable land for a shorter part of the year.

Each nation will have specific crop problems of its own, some of which are being attacked now and have been for years by the introduction of improved farming methods. There must be added to this the possibility of producing more on the suitable land without bringing into cultivation the marginal land, including that which slopes to such a degree as to be eroded excessively. There must also be increased disease resistance built into the plants because of the great difficulty in paying for insecticides, fungicides, and the like in the underdeveloped countries.

The importance of new plant varieties to nations recovering from war or from a status of underdevelopment is indicated by the fact that the FAO considers one of its valuable efforts to be the hybrid corn program in Europe. This brought plant breeders from various countries together in an organization that developed a carefully prepared corn-breeding and testing program. The FAO estimates that corn production in Europe was increased by $24 million in 1952 and by another $40 million in 1953 over what it would have been without the use of hybrids. Sixty-four million dollars is more than FAO's total budget through 1955. FAO's expenditure on the hybrid corn program had been only $40,000 through 1955. The above-mentioned benefits had come from planting only 6 per cent of the total European corn area in hybrid seed. The first step, which was to use the most suitable U. S. and Canadian varieties in Europe, was followed as quickly as possible by the development of national programs to breed hybrids especially suited to local environment.

In the Near East, the Mediterranean area, and parts of Africa, the FAO has cooperated in the breeding of wheat and barley resistant to destructive diseases. In Iran it has instituted similar programs on wheat, barley, and cotton. In the Far East, its activity has been strongest in rice-breeding projects where it should be noted that, of some 5,000 varieties of rice known throughout the world, about 2,000 varieties are known in India alone, where only 30 varieties are grown and only 4 possess attributes other than mere compatibility with the climate. A major portion of the effort in the Far East has been devoted to the development of hybrids between Oryza sativa, var. indica, the low-land rice; and Oryza sativa, var. japonica, the upland rice. The objective, of course, has been to combine the best characteristics of each in a single variety.

In 1955, second-generation seed of about 200 crosses were being grown at experimental stations and the total expenses of the program had still not exceeded $26,000. The magnitude of this and the hybrid corn program should be considered in relation to any of 100 or more industrial research efforts in the United States. The potential payoff of these new-variety development programs demands a many-fold greater research investment. This is especially true when it is realized that the 2 per cent annual increase in food production in the underdeveloped countries of the world recommended by the Bangalore Conference of 1953 would call for an annual investment of approximately $2 billion. Such capital is just not available to these nations. It would appear to be much more economical to grow more per acre and to lose less to disease, and this calls for improved plant varieties.

Mutations, changes in the potentially inheritable gene structure of the chromosome, are believed to be produced in several ways. There appears to be a spontaneous or accidental modification of the gene resulting from something which happens to the mother gene or to the daughter gene, which then becomes a part of the chromosomal structure. The other general method of genetic mutation is by means of radiation. It

has been suggested that the evolution of life on earth has received its mutational contribution through the radiation from terrestrial sources including, for example, K^{40}, or, on the other hand, from space through the agency of the cosmic rays. The result has been an exceedingly slow but important production of mutations which, in combination with selection, has resulted in a net beneficially evolutional process. It is to be emphasized that the modification of a gene in the daughter reproductive cell will probably be recessive for the species involved and so may be reproduced for several generations without noticeable effect until by chance it is involved in the reproductive process with a similar gene, thus leading to perpetuation of the new genotype.

There is not yet evidence that there is any one stage in the growth of a variety at which induced mutation is most effective. Whether in the embryo, the young, or the adult, the effect seems to be about the same. The use of radiation, at first X-rays and most recently radioisotopes, has made possible the production of allelomorphs at a rate several thousand times greater than previously. These induced changes were first noted by the Nobel laureate, Dr. H. J. Muller in 1927. Even after that, many investigators felt that the inducement of mutations was exclusively harmful, producing monsters or being lethal. Further studies, however, led to the general conclusion that the results were not far different from those of spontaneous mutations, that decreased viability was prevalent in the homozygous state and when lethal in that state proved to be detrimental even in the heterozygous state. The fact remained, however, that even though several hundred harmful changes were produced, there would be one or two which showed positive results and could be potentially useful as genetic material. This means in essence that an experimental station devoted to plant improvement through mutational changes and hybridization can increase its productivity considerably without expansion of facilities beyond the adoption of radiation procedures.

The hybrid corn[7] of the United States has been developed without the use of radiation but rather by selection, hybridization, and selection again. At the Brookhaven

Gamma Radiation Field there has, however, been a great deal of research on the production of endosperm mutations in corn. It has been observed that there are differences in sensitivity depending on the stage of the meiotic cycle. Very nearly all of the American corn crop comes from hybrid seed. This situation has contributed greatly to the rapidly expanded yield per acre during the last 25 years.

In Table 3, the steady increase in corn per acre in the United States from 1934 to the present is shown. In Table 4 the concurrent increase in acreage planted to hybrid seed is presented. The figures of Table 4 are even more striking if it is noted that in 1957 the acreage of hybrid corn in the north-central region, or corn belt, was 97.3 per cent of the total rather than 92.5 per cent for the nation as a whole.

Research in Sweden on the induction of positive mutations has dealt mainly with barley and wheat. With barley, the resultant variations have ranged from scarcely perceptible changes to most profound alterations. Even those greatly altered have turned out to be surprisingly productive. The Swedish investigators have a group of about 75 so-called erectoid mutants of barley which so far are believed to have resulted from 16 to 20 gene-locus changes. The production of both grain and straw among these mutants is about that of the mother strain but the stiffness of the straw is far greater, thus combatting lodging tendencies. Some of them mature earlier, some have higher protein content, some are able to utilize to the maximum higher nitrogen additions. Other mutants, not in the erectoid group, thrive even with relatively poorly nourished soil, having, in addition, an increased resistance to certain fungi.

This case demonstrates that a wide variety of new characteristics can be built into a food crop not so much by design in the production of the mutations, but by being alert to the breeding stock resulting therefrom and making the most of it. Furthermore, in Sweden, a newly developed variety of yellow lupine (Lupinus luteus) is now grown as a cover crop at higher latitudes than has been possible in the past. In this case, it has become especially important to breed earliness into the seed stock. Traditional

TABLE 3. UNITED STATES ACRE YIELD OF SHELL CORN OF 56 POUNDS/BUSHEL(8)

Year	Bushels/Acre
1934	15.7
1935	24.0
1936	16.2
1937	28.1
1938	27.7
1939	29.2
1940	28.4
1941	31.1
1942	35.1
1943	32.2
1944	32.8
1945	32.7
1946	36.7
1947	28.4
1948	42.5
1949	37.8
1950	37.6
1951	36.2
1952	40.7
1953	39.9
1954	38.1
1955	40.6
1956	45.7
1957	47.1
1958	51.8
1959	51.5

TABLE 4. PERCENTAGE OF UNITED STATES CORN ACREAGE PLANTED TO HYBRID SEED

Year	Per Cent
1934	0.4
1939	22.5
1944	59.2
1949	78.3
1954	87.3
1957	92.5

methods of hybridization and selection become slow and tedious. X-irradiation of lupine seeds produces more and greater variations, and selection for earliness became successful without loss of yield. The Svaloef white mustard is an X-ray-produced variety now available in Sweden, and producing 7 per cent more oil than the mother strain. Other commercial Swedish products of the X-ray method are the Stralaert pea and the Schaefers Universal Phaseolus bean.

Disease resistance has been bred into economically important plants frequently in the past. Irradiation has accelerated such processes and has resulted, for example, in resistance to stem rust of oats. Thermal-neutron irradiation has aided in obtaining Tama variety oats with improved resistance to Victoria blight. It is interesting to note that a built-in freedom from crown rust often carries with it a susceptibility to Helminthosporium blight. Conventional genetic studies have not broken this association. Preliminary results with radiation appear to offer promise that resistance to both afflictions can be achieved. The importance of new rust-resistant varieties should be kept in proper perspective, however, since there is evidence that rusts themselves undergo natural mutations more rapidly than resistant grain varieties can be developed and planted economically.

French and Vietnamese geneticists are working on rice improvement in the Associated States of Cambodia, Laos, and Vietnam. The rice seed improvement program has been in progress in Thailand for about 10 years. Ten-year development plans in Malaya, North Borneo, and Sarawak include programs on higher yielding strains of rice.

Of 143 apple varieties with known parentage marketed in the United States and Canada, about one-fourth have originated as bud sports. Research is currently concerned with the radiation treatment of scions and seedlings to induce bud sports at a greater rate. Mutations in color and shape of fruit as well as in ripening time have been obtained.

With further reference to barley, the effects of the type of radiation as well as intensity are being studied. It has been found that the mutation frequency increases more rapidly with ion density than does lethalizing action. It is gratifying to note that, whereas the lethalizing action of cyclotron fast neutrons (400 to 800 ion pairs per micron) is for barley about 20 times that of cobalt-60 gammas (8 ion pairs per micron), the mutagenic efficiency is about 40 times as great, thus adding twice as many mutations at the 50 per cent survival point. In the production of the previously mentioned erectoid mutations, the efficiency was about 25 per cent with X-irradiation (ca. 100 ion pairs per micron), 50 per cent with cyclotron-produced neutrons (400 to 800 ion pairs per micron), and nearly 100 per cent at a pile center (1000 to 3000 ion pairs per micron). Caldecott[9] confirms these observations in general and adds that the efficiency of X-rays per r unit in producing genetic changes and lethality can be increased approximately tenfold if seeds such as those of barley are presoaked in water for 8 hours at about 22 C.

In a more extended study of the relation between dose and mutation rate, Singleton, et al.[10], have reported the results charted in Figure 1. The data came from cobalt-60 irradiation of more than a million kernels of corn and report all somatic mutations greater than a trace in the P/p gene.

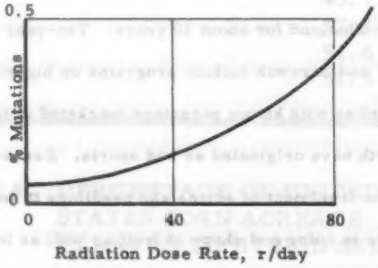

FIGURE 1. DOSE RESPONSE OF SOMATIC MUTATIONS IN P/p STOCK OF CORN

Although little has been done to put radiation for mutagenic purposes on a commercial basis, the Nuclear Engineering Department and the Biology Department of Brookhaven National Laboratory designed a machine housing a 200-curie cobalt-60 source which is supplying chronic gamma radiation to plant stock. It is estimated that the machine will cost not more than $5,000, thus furnishing a fairly reasonably priced radiation mutagenic tool for qualified scientists anywhere in the world.

Ehrenbert, Granhall, and Gustafson[11] point out that most agricultural species, even the high-bred ones such as barley, wheat, or corn, are still old-fashioned in spite of the intensive breeding work since the turn of the century. There is serious need for their reconstruction to fit more precisely into present-day, advanced farming methods or even, insofar as possible, to fit into what farming can be predicted to be 10 or 20 years from now. For example, the internode structure of barley should be more like that of wheat, whereas the cross-sectional area of wheat-straw should be more like that of barley. These investigators believe that substantial progress in such directions could be made by induced mutations. They also recommend increased efforts toward greater grain production in corn with decreased vegetative system.

Barring a catastrophe, the population of the world will most certainly increase at something like its present rate for several decades. For this reason alone, more food and nonfood agricultural products will be needed every year. If, in addition to this, it is desirable to contribute to decreased death rates in the underdeveloped countries, especially among children, and if it is desirable to increase the vitality of their native populations, one step must be the supplying of more and better food on the spot. Until individual incomes in the underdeveloped nations increase several-fold, there will be little money to spend on imported food. Accordingly, human nutrition will of necessity be supplied almost entirely by what can be grown on the land of the country in question plus the animal foodstuffs derived from the products of the same land. In combination

with the continual program directed toward improved farming practices, much appears to be achievable through the adoption of better varieties of food and forage plants.

The program of past years which has dealt with the selection and hybridization of naturally appearing mutants and sports can be accelerated enormously through the application of radiation from various sources. Serious consideration should be given, therefore, to an expanded program of research in this country and, especially, on the scene in the underdeveloped countries with the purpose of producing new varieties of economically important plants as rapidly as possible and, in each case, tailored to fit the specific needs of each country. Some of the results from this scientific pilot planting could demonstrate the degree to which the underdeveloped country could increase the per-capita calorie intake of its population, the nutritional level on a quality basis, the infant survival rate, and the general vigor of its people. As has been pointed out, the superposition of the utilization of radiation on a crop-improvement program is comparatively inexpensive and can compress an extended time schedule into one which can help substantially in a very few years.

Eradication of Insect Pests Through Male Sterilization

The 1952 Yearbook of the United States Department of Agriculture estimates that agriculture in this country suffers a total annual loss due to insects amounting to $4 billion. The war against plant-damaging insects has ranged from laboriously picking beetles off potato vines through the application of various insecticides on the surfaces of plants, to more recent uses on a limited scale of systemic insecticides. Insects damaging animals have not become so well known to the general public and their damage is not so obvious. Losses attributable to them are great, however, not so much through actual death of livestock as through impaired health and damaged hides. Combatting insect pests of domestic animals is difficult for various reasons. For one thing, animals tend to range and so not only must be rounded up for spraying or dipping but also

are subject to reinfestation soon after treatment. In addition, the use of the enzyme-inhibiting insecticides on livestock, particularly dairy animals, is frowned upon by health authorities. Complete eradication of insect pests would be highly desirable.

A rather startling application of radiation in this connection was first tried on a full-scale basis on the island of Curacao, 40 miles off the coast of Venezuela, where an isolated area permitted a somewhat idealized study of the practical value of a method which had shown promise in small-scale experiments. An insect pest was bred out of existence by releasing radiation-sterilized males.

Callitroga hominivorax, the screw-worm fly, is a serious pest of domestic and wild animals in warm climates. It has been estimated that it causes annual losses to livestock in the southeastern United States ranging from $10-$25 million. Normally the population of this insect is not large by entomological standards. It does not migrate over great distances and, which is probably most important, for the method that was used, the female accepts only one fertilization.

The screw worm was indigenous to areas of the United States having the mildest winters. During warm weather it would migrate northward to the Sacramento Valley and in the midwest perhaps as far as Kansas, but could not winter-over in such regions. It was seldom found very far East of the Mississippi River until 1933, when infested cattle caused the insect's accidental introduction into Georgia and Florida. Peninsular Florida can still be considered as one isolated region of year-round screw worm infestation. The elimination of the population there, followed by care in inspecting cattle immigration could remove that area as a screw worm problem.

The larva of the screw-worm fly is parasitic. Eggs in masses of about 200 are deposited on abrasions in the skin of warm-blooded animals. After hatching in 12-24 hours, the larvae feed and attract more flies. Bushland et al.[12], described untended animals as being literally eaten alive. After 5-6 days, the larvae burrow into the soil and pupate. The parasitism of this insect is obligatory and if the host animal dies

before the larvae have completed two-thirds of their 5-6 day development on it, the latter cannot survive.

It was found that the gamma irradiation of a laboratory population of the screw-worm fly could be carried out so that at a dosage of about 5,000 r, essentially all, male and female, of this group would thus be sterilized. When released, the result was that there would be no progeny of the infertile females or as a result of the matings of the infertile males. By repeating this process a few times then, it might be expected that the species could be eliminated. Strictly speaking, the males should not be considered as sterile because they can still produce sperm which can fertilize eggs. Practically, however, they may be called sterile because their progeny die as embryos.

X-rays could be used for the irradiation of small colonies, but cobalt-60 gammas were found to be much more economical for larger numbers.

The procedure was first carried out successfully on Sanibel Island off the Florida Coast in 1953, and then, by arrangement with the Dutch government, on Curacao, the area of which is about 170 square miles. Starting in August, 1954, about 400 sterilized flies of each sex were released on each square mile every week. This was continued until January, 1955. After October, 1954, no fertile eggs were recovered from experimental goats on the island. The fly appears to be extinct now on Curacao and the livestock is reported to be in considerably improved health. The main application for this method of eradication was expected to be in southeastern United States. Accordingly, a similar operation was set up on a 2,000 square mile area around Orlando, Florida. The results have been successful and a still larger program was established on 50,000 square miles in southern Florida. Fifty million sterile flies per week were produced. E. L. Peterson,[12a] Assistant Secretary of Agriculture, reports that since the winter of 1957, losses attributable to the screw worm have been negligible. The cost of the campaign was about $7 million and in only two years more than $20 million of losses have been avoided. If domestic animals were the only ones attacked by the

screw-worm fly, control might be achieved by periodic spraying with a larvacide. The multiplication of the species seems to occur, however, on wild and neglected domestic animals.

The question arises, of course, whether eradication by this means is possible for other economically serious insect pests. There has been some conjecture and a stated belief that it could be done where a number of requirements can be met. The natural population must be rather low or must be capable of being reduced temporarily by other means. The insect must be rearable under laboratory conditions and the mating behavior of the males must not be adversely affected by the sterilization. Preferably the females should mate only once but it remains to be shown by experiment that this is essential. The area for the campaign should be isolated or should be protectable by quarantine. All of these requirements may be subjects for further research to determine to what degree they may be relaxed.

Candidate pests include several destructive fruit flies in Hawaii, the islands of which furnish an attractive degree of isolation. Mosquitoes in some regions, the Mediterranean and Oriental fruit flies, the melon fly, and the tsetse fly in certain parts of Africa are other possibilities. Research on these and other insect pests might well be undertaken as part of an international atomic-energy program. The availability of cobalt-60 or possibly other radioisotopes which may be equally desirable, or even more so, should be helpful to the areas involved.

Jaynes and Godwin[13] have reported on the sterilization of the white pine weevil using cobalt-60 gammas at an optimum level of 5,000 to 10,000 r. Their intention was not eradication but, rather, to render them harmless before releasing them for a dispersal study. The white pine weevil presents a different situation from that of the screw-worm fly because the female is polygamous. The study indicated, however, that sterilized males were able to negate previous insemination by a normal male; the reverse was also true. Such findings as this emphasize the need for considerable

research if the radiation sterilization of certain male insects is to be considered seriously as a method of control.

At the present developmental stage of this means of insect eradication, it is especially difficult to separate research and development costs from the actual expense of eliminating the screw-worm fly from either Curacao or from Florida. It seems likely, however, that they were much less than the estimated[14] annual screw-worm damage in Florida: $20 million. It has been estimated further that if the method could be applied to the population of this insect west of the Mississippi, annual losses of $35 million could be eliminated. Other innovations of this and related sorts providing an essentially one-time campaign for the elimination of various damaging insects could conceivably produce control of the cotton boll weevil which causes $250 million damage each year; the sugar cane borer which destroys $4 million worth of crops per year; and others in this country and elsewhere in the world. Such tentatively attractive economics seem to recommend further research at an accelerated pace to avoid recurrent annual losses and to hasten the day when campaigns against the insects will stop highly wasteful and probably unnecessary losses.

Fertilizers

Probably the earliest agricultural studies using radioisotopes were those dealing with mechanisms of fertilizer uptake by plants. Of these, the research on phosphorus was first, and has proved to provide the majority of published papers. P^{32} is well suited to agricultural research in having a half life of 14.3 days, which is long enough for the types of experiments involved, but is short enough to cause substantial lack of interference after a period of months in the event that additional radioisotopic research is contemplated in consecutive years. A period of 120 days is generally considered to be the longest suitable one for use of P^{32}.

This section on radioisotopes in fertilizer studies will necessarily concern itself with only a few aspects. Otherwise it would be entirely too long and too diffuse. It can be said, to begin with, that here again the increasing population of the world and the increasing per-capita calorie intake of the populations of the underdeveloped countries make it essential that acreage yields of agricultural products, particularly foods, be augmented during the foreseeable future. One of the ways of accomplishing this will be through expanded use of fertilizers. Especially, as we give more consideration to the currently underdeveloped countries, we must think of the cost of fertilizers, including particularly shipping costs from industrial centers. Accordingly, anything that can be done to decrease the actual amount of fertilizer applied to the soil while still providing an adequate amount for the plants themselves, will help in improving the reception given to this means of yield increase.

The three major elements of mixed fertilizers are nitrogen (N), potassium (K), and phosphorus (P). A number of other elements are required by plants in varying amounts. Included among these are calcium and iron as well as a large group of so-called trace nutrients. Soils differ enormously in their contents of fertilizer constituents. Phosphorus, for example, exists in many soils but there still seems to be a need for added quantities if high-yield crops such as corn and tobacco are to thrive. A question which had existed in the minds of agricultural, experts for many years had to do with the relative amounts of phosphorus (a) already in the soil and (b) added in fertilizer used by plants. With the availability of P^{32} soon after World War II, it became possible to label the phosphorus-containing compound of the fertilizer and thus identify the sources of the element as it appeared in the plant. As might be expected, various crops showed different behaviors. In addition to this, the several phosphorus compounds in the fertilizer behaved differently. It can be said, however, that phosphorus shows low mobility in the soil and, partly because of this, furnishes a rather small percentage of what is taken up by the plant when it is broadcast in fertilizer.

Commercially, phosphate fertilizers include superphosphate, calcium metaphosphate, dicalcium phosphate, liquid phosphoric acid, and monoammonium phosphate. In acid soils, dicalcium phosphate appears to be quite satisfactory. In alkaline soils, however, the several forms rate as follows in decreasing order of desirability:

Superphosphate and monoammonium phosphate

Calcium metaphosphate

Dicalcium phosphate

Tricalcium phosphate.

Quite generally the research with labelled fertilizers has demonstrated the effectiveness of superphosphate.

The relative uptake of new and old phosphorus in the soil by a crop is influenced by the rate of fertilizer application as well as by the amount of available phosphorus in the soil. In one crop studied, the percentage of phosphorus derived from applied P^{32}-labelled fertilizer was significantly decreased by the presence of phosphorus which had been applied to the plot 8 years before.

Phosphorus in the usual fertilizer compounds migrates suprisingly little. That is monocalcium phosphate labelled with P^{32} moved only 1.25 inches in a clay soil and 4 inches in a loam. Phosphoric acid, however, in irrigation water penetrated to a depth of about 12 inches even though the water continued for 8 inches beyond. Even after 43 days, 86 per cent of the phosphorus was still in the top 6 inches. Although another investigation showed that only 2.5 to 5.2 per cent of the superphosphate top-dressed on permanent pasture moved more than 1 inch, the method of application was found to be surprisingly effective in growth promotion on conventional meadows and on established stands of legume hays.

The limited migration of phosphate fertilizers has shown that corn soon after sprouting may make use of the current season's fertilizer, whereas the root system of the plant as it grows will draw on the phosphorus inventory of the soil.

Other nutrient elements have been studied in somewhat the same way as phosphorus. The mobility of potassium using K^{42} was found to be predominantly less than 1.6 inches. With Ca^{45} it has been shown that the various calcium compounds differ considerably in their utility, particularly in soils of different acidity or alkalinity. The average mixed fertilizer in the United States contains 17 per cent CaO. Studies have shown, however, that plants obtain only 2 to 6 per cent of their calcium from the fertilizer. In contrast, 25 to 36 per cent of their phosphorus needs were derived from that source. The efficiency of utilization of conventional zinc fertilizer applications was relatively low and was harmed by lime additions.

Some of the secondary nutrients such as iron and zinc are made much more available to plants if they are applied to the soil in the form of chelates. Then they are not subject to fixing effects of alkaline soils.

In research investigations on the points of absorption of nutrients into plants, a considerable amount was found to be introduced through the leaves. Radioisotopes assisted materially in demonstrating the absorption and translocation of various elements. Those which are taken up by leaves and translocated include nitrogen, phosphorus, sulfur, potassium, sodium, manganese, zinc, copper, chlorine, and rubidium. Calcium, strontium, barium, cesium, iron, molybdenum, and ruthenium are absorbed by the leaves but remain at the point of entry. Slightly acid solutions will be absorbed more readily than those which are alkaline. The aforementioned materials, as well as sugars, can also be leached out of the leaves during heavy rains. It has already been shown that the application of some nutrient elements, nitrogen especially, could be made through the leaves and apparently with some economy of materials in comparison with fertilizer applications to the soil. In fact, substantial quantities of nutrients are also absorbed through the bark. Solutions of labelled potassium carbonate and phosphoric acid applied to the bark led to detection of radioactivity in the branches as far as 24 inches above and below the points of application. This occurred within 24 hours and

during the months of February and March, even at temperatures below freezing. Accordingly, the potassium and phosphorus were available where needed when the buds began to swell and new growth was imminent. This procedure is applicable not only to healthy trees but also to those bearing injuries.

Returning to the more generally useful idea of feeding plants through their leaves, it is significant to note that 95 per cent of the phosphorus so applied has been observed to be absorbed. This is far more than can be achieved through the roots. In experiments with beans, the foliage was shown to be 25 times as efficient in phosphorus uptake, from phosphoric acid, as the roots. Leaf feeding is generally supplemental to root feeding and can be especially useful during critical periods of flowering or fruiting when nutrients demands are high. Properly timed foliage sprays can supply 25 per cent of the phosphate needed in fruit growth. Burr, et al.[15], report on the basis of experiments with P^{32} that all of the phosphorus requirement of sugar cane can be supplied by spray. Under the best conditions, 75 per cent of the phosphorus sprayed on as monopotassium phosphate was absorbed. Potential savings, to be confirmed by actual calculations of economics, are strongly indicated, even more so if one considers the rapid and firm fixative action of Hawaiian soils for phosphate which makes fertilizer applications almost ineffective.

Further results from the experiments with bean growth have demonstrated the increased absorption of phosphorus with decreased pH. Of the three compounds, potassium, sodium, and ammonium phosphates, the last named showed the greatest tolerance of high pH which, however, could not be carried above about 5. In studies of potassium absorption, the citrate at pH 8 was absorbed better than the chloride or phosphate.

In general, wetting agents help, but some detergents should be avoided because of their harmful effect on speed of absorption. One position on the leaf is about as good as another. The top side is a little better than the under side. Light is not necessary.

Of the various forms of nitrogen, urea is probably best for foliar application. In some cases, the entire nitrogen requirement can be satisfied by a few sprays. The potentialities for plant nutrition via the leaves are great. It must be kept in mind, however, that each application is performed quickly and that the absorption and translocation are rather rapid. The method can provide some or all of certain nutrients. It can give a distinct boost when needed. The nutrient reservoir effect of the soil should not be ignored, however, in this connection.

There have been numerous apparent anomalies in nitrogen fixation by plants. It is known, of course, that nodulated varieties fix nitrogen through the agency of their associated microflora. It has been observed, however, that the so-called Broadbalk field at Rothamstead gives a steady yield of wheat at a low level, year after year without added nitrogen. The same behavior has been noticed in fairly arid wastelands of the United States and Australia.

A 24-year apple-growing trial in Scandinavia showed no reduction in tree size or yield in spite of failure to add nitrogen fertilizer. In another case, it was demonstrated that tung trees would thrive while more nitrogen was being removed in the crop than was being applied as fertilizer. A number of other such examples could be cited, including one pine grove which apparently was associated with an average increase of 32 pounds of nitrogen per acre per year without any additions as fertilizer. Other experiments have been carried out which eliminated rain as a source even through it could be calculated to add considerably less than 10 pounds of nitrogen per acre per year. Research is under way, therefore, at the present time using N^{15} to determine just how non-leguminous plants accomplish nitrogen fixation. The results may well be of considerable assistance in achieving increased yields of crops in areas where nitrogenous fertilizer additions would be difficult as well as expensive. The use of fertilizer commercially always involves economic considerations. Accordingly, in the various countries of the world there will be special situations based on nature of the crop,

nature of the soil, farming methods, moisture availability, and the cost of obtaining and applying fertilizers. The research which has been done so far in this area using radioisotopes will be extremely helpful. There will necessarily be more, particularly of an applied nature, which may well form a part of this country's international program. Its results could lead to still further self-sufficiency in the basic food materials in the underdeveloped countries.

Physical Properties of Soils

Agriculture consists of crop production by growing plants in soil. The mere fact that there is a branch known as hydroponics does not invalidate this statement in the least because non-soil culture constitutes an extremely small fraction of 1 per cent of agricultural operations.

Soil serves several purposes. It is a support for the plant and its roots whether this be a cucurbit or a Sequoia. Soils are, or should be, a porous medium capable of absorbing water when there is an excess and giving up water when the supply is deficient. It can continue to do this some of the time at least while still being porous to air. Soil is a storage medium for mineral nutrients, generally providing an ion-exchange function for a number of essential elements.

In evaluating soil for the growing of new crops or new soil previously fallow to be put into cultivation, a knowledge of its density, water porosity, and gas permeability are highly desirable. Such properties are subject to the operation of a crude but illustrative extension of the Heisenberg Uncertainty Principle. As we perform operations on the soil, the measured physical properties become less significant. Ideally, the characteristics of the soil should be determined without disturbing it. Radioisotopes have provided means of doing this and have the added advantage of giving a fairly simple test method in each case which, of course, is applied in the field.

The bulk density of soil can be measured by back scattering of gamma rays of 1 Mev or more. Cobalt-60 or Cl^{134} can be used as the source. Both source and counter can be placed on the surface of the soil and the observed rate compared with water or other standard. Although the further research needed to perfect this method can be done almost anywhere in the world, the results will lead to the production of a scientific tool which can be used in soils research in the United States and elsewhere as well. Thus soil-density research as such is not something which would fit into an international atomic-energy program. The studies of soils throughout the world using radioisotopes, many of which might come from this country, will, however, be valuable in aiding agriculture generally.

Aeration of roots is essential to optimum plant growth. Lack of aeration along with adequate or excessive water will result in poor growth and chlorotic symptoms. This behavior is often seen in the United States in low-lying corn fields during the early summer when heavy rains may make reseeding necessary. The home gardener is repeatedly warned to provide good drainage for a number of decorative plants, true lilies in particular. A number of chemical methods have been used to measure the rate of aeration of soils. In most cases, however, a gas has been used which is somewhat different in molecular weight from the soil atmosphere. This introduced the confusing factor of mass flow superimposed on diffusion. With the availability of C^{14} it has been possible to use labelled CO_2 in measurements of its diffusion through soil containing an atmosphere of normal CO_2. It is believed that research on the properties of soils in countries undergoing rapid agricultural development will profit greatly from a means such as this for measuring gas permeability, which is one of the most important factors of a good soil.

The moisture-retaining properties of a soil are obviously important in the growth of the plant. In some of the more populous parts of the world, agriculture can accept the supply of rainfall and its fluctuations during the growing season without experiencing

serious damage to crops. In other parts of the world, supplemental water must be provided through irrigation and, in still other parts, essentially no moisture is derived except from irrigation. A striking illustration of the last is observable in the Nile Valley, where the bright and healthy green of the irrigated crops does not gradually shade off through a band of decreasingly well-nourished plants, but stops abruptly, giving way to the sand of the desert. A quick, inexpensive and portable soil-moisture-measuring instrument is desirable then for studies of soils on the frontiers of agricultural development. It is also desirable for fairly routine measurements of moisture content to determine when and to what extent irrigation water should be introduced. It has been found to be quite effective to place a source of fast neutrons on the soil's surface or in a shallow well. The source is usually a radium-beryllium combination. The fast neutrons are slowed by hydrogen nuclei and are sensed by an instrument placed close to the source. The results seem to be reliable and are more rapidly obtained than those by (1) oven drying of soil samples, (2) electrical-conductivity measurements, (3) penetration resistance, (4) heat-transfer rate measurements, and (5) tensiometer. There are other radioisotopic methods of soil-moisture determination, but they require the drilling of two holes in the soil, a shortcoming of nonradiation methods.

Proper agricultural management not only on irrigated land but on some which is not irrigated as well, requires a reasonably accurate prediction of the water which will be available as a result of the melting of snow over the drainage area involved. In a manner somewhat analogous to the moisture content in soils, it is now possible to measure the depth of snow. Thus a survey made shortly before the spring thaw in the mountains comes will provide the information needed.

The foregoing makes clear the valuable developments in methods of measuring the physical properties of soils and, as one predicts water supplies several months ahead, one can also predict the achievable water content during the growing season.

Radioisotopes have provided quick, portable, and comparatively inexpensive methods of obtaining this information which can aid agricultural production in all parts of the world. The results can be greater agricultural production and, what is almost as important, more reliable production from year to year. As part of an international program of atomic-energy research in the general area of agriculture, the four methods just described can be used without much additional development work. There are, of course, other problems of soil management that need better solutions. Attention should be given to the contribution which radioisotopes can make. In Hawaii more than half of the million-ton sugar crop is grown under irrigation. It is important then to know how uniformly the water is being distributed over the fields and especially important in view of the increasing practice of adding soluble fertilizers. This can be done by adding tagged compounds and checking for their distribution throughout the growing area. Field layouts and grades can be adjusted on the basis of the findings. Phosphorus^{32} was one of the early available, potentially suitable radioisotopes but, as pointed out earlier, Hawaiian soils are notorious for their rapid and complete fixing of added phosphorus. Rubidium^{86} does not suffer from this objection. It emits strong betas, has a suitable half life of 19.5 days, and behaves chemically like potassium, an agriculturally important nutrient element. It has the slight objection that it also emits gamma rays, but this characteristic merely adds to shipping and storage costs. Over 100 tests in practically all of the irrigated sugar cane areas of Hawaii have shown moisture variations so great that immediate steps to reduce or eliminate them are indicated. To put enough water into the soil at some point, it was found necessary to flood other sections with three or four times the necessary amount. This is wasteful if it is irrigation water alone; it is especially wasteful if fertilizers are included. This added example will illustrate how resourcefulness and ingenuity as well as scientific need will call on radioisotopes in many areas of research in agriculture throughout the world. This country is in a position to assist both by supplying knowledge and by

supplying the needed isotopes. It is suggested that we do so in order to aid the basic human needs satisfied through an efficient agricultural industry.

Insect Habits and Insecticides

Earlier in this section, brief reference was made to the damage done by insects in the entire field of agriculture. This was followed by a review of the eradication of certain insects using radioisotopes. Since this procedure is of very limited usefulness, attention will be given now to the use of radiation in defining certain habits of insects which can be taken advantage of by reducing their numbers rather than actually eliminating them. Further, there will be a discussion of radiation as it points to more effective and more economical use of insecticides. All of these matters are of importance to the agricultural countries of the world and may well fit into an American program of international cooperation of atomic energy.

It has become a fairly common procedure to tag insects with radioisotope-containing compounds for the purpose of measuring their range. The results can be helpful in determining when and how to apply insecticices, thus leading to economy of quantities and to avoidance of otherwise indiscriminate application. The tagged compound can be applied directly to the insects or it may be ingested. The method will undoubtedly continue to be appropriate to the studies of insects in many different countries in order to aid control programs. It is interesting to note that P^{32} labelling of screw-worm flies was an important part of the eradication method described earlier. Limited range plus isolation were important to success, whether on Sanibel Island, Curacao, or most of the peninsula of Florida. The labelling was accomplished by rearing the larvae in a medium containing 0.02 to 0.05 microcuries per gram. Identification was possible as long as 4 weeks afterward.

Grasshoppers are often a serious pest. It is known that the grasshopper, Melanoplus mexicanus, travels as far as 240 yards in 6 days on bare, cultivated ground.

These insects demonstrate no ability, however, to orient themselves and move toward a food supply. R. W. Smith[16] became curious about the distance of movement in an area of adequate food supply. Accordingly, he and his co-workers labelled a colony of the same species by supplying a diet in which P^{32}-labelled potassium phosphate was added to a bran and molasses mixture (2 mc in 1 pound of bran plus 50 ml of molasses). The grasshoppers to be identified were released in an alfalfa field and it was found that none moved more than 30 yards during a 20-day period. An incentive to dispersal was provided by the somewhat denuded condition of the field at the release point. On the twelfth day, however, 13 radioactive grasshoppers were captured on a single square yard at the original point of release.

It had not been known whether white pine weevils would take wing and fly freely until a group were labelled by an application of $Sc^{46}Cl_3$. This experiment gave evidence that they would do so and would travel over distances as great as 100 yards. Wire worms were identified[17] by attachment of a bit of cobalt-60 to their bodies. Their movements could be followed even underground. It was found that wire worms tended to avoid the insecticides lindane and aldrin but not dieldrin and heptachlor. A similar technique had been used in 1946 to follow the movements of click beetles through the soil. A small disk of Ra^{226} was attached to the underside of a wing of each specimen.

A potentially useful phenomenon is illustrated by the fruit fly, Dacus dorsalis, which will absorb P^{32} from a labelled sugar solution. It has been found that the female flies lose their radioactivity more rapidly than the males because it passes into the eggs. In studies of the plum curculio, Zn^{65}, Sr^{89}, and Zr^{95} have been used. The last is particularly useful because the gamma radiation is detectable at some distance.

A number of insects cause damage by the transmission of disease rather than, or in addition to, that produced by defoliation. The tarnished plant bug is blamed for the transmission of a number of plant diseases. Radioisotopes have been used in demonstrating that this insect injects 0.05 to 0.25 x 10^{-3} ml of saliva at each feeding on plants

such as beans. This will give an index of the material available for conveyance of disease organisms from plant to plant. Although it is hazardous to predict future applications of the results of basic research, it may well be mentioned that the amino acids acids essential for insect nutrition have been distinguished from those that are nonessential. C^{14}-labelled glucose was fed to third-stage larvae of the blue-bottle fly. Three days later, the amino acids extracted from the bodies were chromatographed. Glycine, serine, glutamic acid, and aspartic acid turned out to be radioactive. These were known to be nonessential. All of the other amino acids found were nonradioactive and were, therefore, not formed within the insect but rather were supplied by their food.

Efforts to reduce agricultural damage by insects have made necessary a constant war on many fronts. Long ago an equilibrium was achieved which was aided by two major factors favoring the farmer. One was simply that the ratio of wild crops to cultivated crops was so great that there was essentially no necessity for pests to seek strange plants, among those being farmed, for the purpose of using them as new hosts. The second factor was the comparatively large population of enemies, whether birds, in the case of many insects, or lady bugs in the case of aphids. As agriculture expanded in general, methods of control became absolutely necessary. Accordingly, sprays and dusts of lead arsenate, pyrethrum, etc., came into widespread use. Naturally, the question of mechanism of poisoning action arose in order to obtain a better understanding, which might lead to more effective and more economical procedures. As early as 1931, Pb^{212} was used to tag lead arsenate to study the absorption and excretion of the compound by the silk worm. The use of radioisotopes for similar purposes has grown enormously during the intervening years. Insect control by means of insecticides is an expensive operation. Needless to say, the losses in the event that such controls are not used would be many times greater. Fortunately, during the early part of World War II, DDT, the first of the contact insecticides was discovered. Many modifications

of it followed rather quickly. This type of insecticide is highly lethal to a great range of insects although not particularly harmful to the arachnids.

A disturbing phenomenon which appeared before long was the development of an immunity toward DDT. A population of house flies, for example, would be highly susceptible at first, but those which were not affected would give rise to progeny which were also immune. Radioisotopes such as C^{14}, P^{32}, and S^{35} have been used to study this problem with the aid of chromotography. Thus it had been shown by chemical methods that resistant house flies dehydrochlorinate DDT to the nontoxic compound DDE. It was not possible to show that there were or were not other metabolites. Radioisotopes, however, have furnished proof that the production of DDE is essentially the only reaction of DDT in resistant flies during the first 10 or 12 hours. The reasoning then is that an added synergist should enable DDT to perform its functions while the dehydrochlorination reaction is suppressed. In a study of diaryl trifluoromethyl carbinols, Tahori[18] found bis(parachlorophenyl) trifluoromethyl carbinol to be most effective. The experiments were performed on the Tel Hashomer strain of Musca vicina, which is about 15 times as resistant to DDT as a Berkeley strain of Musca domestica. The synergist produced highly satisfactory results on the resistant flies. It may be pointed out that the problem of insect resistance to DDT is an especially acute one in Israel. There and elsewhere effective synergists will be especially valuable. The fate of DDT, as described above, has been shown to be very similar for certain other insects. In the roach, however, which is not nearly so susceptible to DDT, an entirely different series of metabolites result and DDE is not detected at all. Unfortunately, perhaps, studies of a variety of insects have demonstrated that developed resistance to DDT involves more than a single process. Accordingly, a substantial research program remains to devise means for the prevention of such resistance in the many insects which are and will be pests.

Parathion is generally considered to be a potent and important contact insecticide. Its action as it demonstrates its effectiveness is to inhibit the enzyme cholinesterase. It has been demonstrated, however, that Parathion which contains the PS group is not a cholinesterase inhibitor but Paraoxon, which contains the PO group is. Research has explained this apparent anomaly by showing that a large variety of insects convert Parathion to Paraoxon in their bodies. A fairly complicated organic compound containing PO groups is known as Schradan. Strangly, Schradan is not a cholinesterase inhibitor. When one of its nitrogen atoms is oxidized in the body, however, it becomes highly toxic and thus has found extensive use in the control of citrus red mites, cowpea aphids, and mosquito larvae. Radioisotopes have enabled entomologists to find that there is a competing reaction of hydrolysis, which is not serious if the pesticide is Schradan. If it is oxidized Schradan, i.e., if the Schradan is oxidized outside the insect's body before it is administered, the hydrolysis predominates to such an extent as to make the material appear to be nontoxic. There is evidence that in experimental warm-blooded animals, specifically the rat, hydrolysis predominates even if the starting material is Schradan. This suggests a comparatively low degree of hazard when using this pesticide for the control of insects in areas inhabited by domestic animals and perhaps humans.

A fairly exact knowledge of the fate of the so-called systemic insecticides, which actually enter into the plant tissues and are transported even into new growth, is clearly necessary. Part of the need rests on the comparatively expensive nature of these insecticides and part of it on their high potential toxicity to warm-blooded animals. Without the availability of P^{32}-labelled compounds, the progress made so far, as well as the research that will be called for on plants and compounds still unstudied here and in other parts of the world, would have been impossible. It has been shown, for example, that in crops such as the pineapple, Disyston, administered to the roots achieves fairly uniform distribution in younger plants and tends to concentrate in new tissue if

the plants are older. A potentially very important discovery has come from the use of p^{32}-labelled Systox on cotton. In its translocation within the plant, very little is found in the nectar. There can be good assurance then that in cotton and other plants showing the same behavior, there will be no contamination of beebread or honey, even though Systox is applied before or during blossom time. It will be recalled that one of the considerable hazards in the widespread use of contact insecticides is destruction of beneficial insects such as the bee, which serve an important pollinating function for many plants. By somewhat the same means, Schradan has proved to contaminate the nectar of mustard and borage. The contamination persists for 4 weeks after spraying and is stable in honey. P^{32} labelling has also indicated that Schradan accumulates to the extent of 8 to 16 ppm in raw cottonseed oil. Fortunately, however, it is practically completely removed during the refining process. Some of the early and comparatively nondangerous insecticides were the pyrethrins. They exhibited excellent knock-down. Because of their rapid detoxification in the insect bodies, recovery was all too frequent. C^{14}-labelled compounds have made it possible to demonstrate that certain materials would interfere with the metabolism of the pyrethrins and thus delay the recovery, allowing the toxic reactions to proceed. Piperonyl cyclonene is one of the most outstanding of these and acts clearly as a synergist.

It may be pointed out without going into detail, that radioactive tracers have been quite useful in studies of potential contamination of foods by pesticides. In some cases, they have provided important warnings; in others they have dispelled fears. An example of the latter has to do with the fumigation of grain or flour with methyl bromide. It is known that a methylation of histidine takes place but it has been satisfactorily proved that the product offers no health hazard. In addition, no vitamins seem to be inactivated. The fumigation of dried fruit with ethylene oxide is also known now not to be dangerous.

Plant Constituents Manufacture – Alkaloids, etc.

A number of economically important products are manufactured in plants and obtained from them by various means. Examples include the alkaloids, natural rubber, turpentine, maple syrup, the steroid precursors, tranquilizers, quinine, nicotine, and others. Many of these have been synthesized in the laboratory; most of them cannot be synthesized economically in commercial quantities. One reason for this is the complicated nature of the molecule, another reason is that the molecule may contain one or several points of stereoisomerism. Synthetic-organic chemists are still handicapped by the extreme difficulty of (a) producing the desired one of a pair of stereoisomers or (b) resolving such a pair completely and economically and, in any case, being left with the undesired one for discard or recycling in the process. Generally, in nature the one desired stereoisomer is produced. An example will be found in the case of monosodium glutamate (often known commercially as MSG). This compound may be recovered from beet-sugar wastes in the laevo-rotatory form which is an excellent food flavor accentuator without objectionable taste of its own. It is used in very large quantities in the Far East and is well received in this country, too. Monosodium glutamate is not difficult to synthesize but the optically inactive form results. Its taste is not by any means pleasant and its flavor-accentuating power is not more than half that of the natural product. Accordingly, the MSG of commerce is, so far, the natural product.

If these numerous plant products desired by man are to be as widely available as possible, it is certainly advantageous to obtain the highest possible yield from the plants involved. Therefore, a knowledge of the mode of synthesis within the plant is needed and varieties producing the largest quantities should be cultivated. There is the question, "when should pine trees be tapped most advantageously for turpentine?" Experiments have been carried out in a 60-cubic-meter chamber containing a 30-year-old pine tree to which $C^{14}O_2$ was supplied. By suitable tracing, an answer was obtained.

Similar work is being done on rubber and cinchona trees and tobacco plants. The synthesis of nicotine occurs in the root of the tobacco plant. The compound migrates to the leaves where it accumulates. It appears then that means should be fairly readily available to produce an unusually high content of nicotine in crops that are to be used specifically for production of the alkaloid. Similarly, it should be possible to produce a low-nicotine tobacco if that appears to be desirable.

For many years to come, there will undoubtedly be a large production of material synthesized within plants. Since these will come from all parts of the world and, conversely, will be shipped to almost all parts of the world, it is rather clear that an international program of research involving atomic energy might well include studies such as these which have such potentialities. It is obvious that making the necessary isotopes available would be a part. It is also rather obvious that much of the research needs to be done in areas of the world rather remote from the United States. Improving the production of rauwolfia, curare, or quinine is undoubtedly accomplished better in Africa or Latin America than in this country.

One other method of applying radioactive tracers, which seems pertinent to the subject matter of this section, has to do with the prevalence and the implications of root grafting in plant colonies. The place of root grafts in the spread of the catastrophic elm disease, Phloem necrosis, is strongly suspected, if not clearly proved. Radioisotopes have shown beyond doubt that a group of pin oaks is actually a colony connected through root grafts in such a way that nutrients and diseases may spread from one to another. Spores of the pin oak wilt disease have been traced from tree to tree, proving that effective control of the disease requires removal not only of the affected tree, but others of the colony as well.

Opportunities for International Cooperation

There is impressive evidence of the benefits to be derived from the application of atomic energy to agriculture. Although the fact has not yet been demonstrated, the evidence suggests that these benefits can be realized for either a well- or a poorly developed agriculture. Because of this characteristic, there appear to be many opportunities for utilizing atomic energy to improve the agricultural output of other countries. Some of the specific steps which seem likely to lead to economic benefits for other countries include the following:

(1) The economic benefits which will be derived from basic research on agricultural science are less immediate and less certain than those which will be derived from applied research. The most immediate benefits will therefore result from stimulating applied agricultural research programs. Basic research programs, in this and other well-developed countries, should continue to supply the fundamental information which such applied research programs need.

(2) Mutagenic research holds promise for producing improved crops for all types of situations, and applied research in this area appears desirable. Such research can most profitably be done under the conditions in which the crops will be used. In this area, the United States can help most by helping other countries acquire the tools, information, and trained scientists for mutagenic research.

(3) Insect eradication has been shown to be possible when specific favorable conditions can be met. Further research will probably extend the range of conditions under which beneficial results can be obtained. A successful application of these principles to the eradication of important insect pests in other countries would help their

agriculture. Again, such research is done most efficiently on the site of its application, so the most effective aid the United States could supply would be the tools and techniques for research in this area.

(4) Tracer studies are providing important new information on the effectiveness of insecticides and on the hazards of their use. The information being obtained can be used directly and indirectly to benefit the agriculture of all countries. Additional research, stimulated in other countries by providing training in the use of the tools and techniques of such research, would further benefit their agriculture.

(5) Studies which are in progress of the methods of utilization of fertilizers by plants should ultimately aid the agriculture of all countries. Such research can best be done in those countries which are technologically strong. The results from such research will help other countries.

Applied research on the specific problems of using fertilizer most efficiently for the soil, climate, and crops of specific countries would be beneficial when it is economically feasible for the country to use fertilizer. Such research can be done in most countries, if tools and training are available.

(6) Tools and techniques being developed for studying the physical properties of soils will be directly applicable to the agriculture of other countries. Instruction in the use of these tools, and the results obtained from their use, will improve the agricultural industry of other countries. Additional research may show other useful applications of atomic energy for soil studies.

(7) Tracer studies of the processes by which plants manufacture economically important products have developed new information on ways to improve yield. Such studies, in other countries, should similarly provide useful information. Such research might be stimulated by supplying the research tools and techniques.

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MEDICAL APPLICATIONS OF ATOMIC ENERGY

To a degree, research in medicine is like that in agriculture as well as many other subjects in consisting of a substantial effort to answer unsolved questions and elucidate mechanisms, plus a large effort to solve pressing and very practical problems. The first, which we might call basic research, occupies a different place in medicine than it does in agriculture or in the other disciplines because it often deals with diagnostic methods.* Specific diagnoses of individual patients often turn out to be research undertakings in themselves. It is a short step, then, from a study of the role of Vitamin B-12 in macrocytic anemia to the diagnosis of pernicious anemia and the detection of hepatitic liver damage. Similarly, radioisotopic methods of locating the boundaries of tumors may have value in other research and can be expected to be published for the benefit of medical science. Such methods may also be of substantial value throughout the world in operative procedures in any nation and on patients of any nationality. At the present time, according to a report prepared by Stanford Research Institute for the Office of Isotope Development of the Atomic Energy Commission[1]**, about 400,000 administrations of radiopharmaceuticals are made annually to humans. Over 85 per cent of these are for diagnostic purposes; the remainder are for therapy. Accordingly, in this review of atomic energy and medicine, there will be frequent references to basic as well as applied research undertakings and to their potential value throughout the world in a program of international cooperation.

Diagnosis

Fortunately for the applications of isotopes in the science dealing with body processes of man and warm-blooded animals, many of the radioactive forms are those of

*For this reason, the term "basic research" as used here does not fall within the scope of the earlier discussion of basic research.
**References for this section are given on page 202.

participating elements. Examples are C^{14}, H^3 (tritium), P^{32}, S^{35}, Na^{24}, K^{42}, I^{131}, Co^{60}, and Fe^{59}. Almost 80 per cent of diagnoses with radioisotopes use radioiodine, generally I^{131}; less frequently the 124, 125, 126, 132, and 133 isotopes are used. Extreme care must be observed, of course, to avoid undesirable side reactions. As one factor, the age of the patient is important. Forty per cent of all radioisotope administrations to humans are to those over 50 years of age and only 2.2 per cent to those younger than 14. About two-thirds of the administrations are to female patients, probably because of their greater susceptibility to thyroid disorders. With adequate care, however, results can be achieved which otherwise are either impossible or extremely difficult. Accordingly, tagged compounds may be used to follow metabolic processes and particularly to observe and to take advantage of tendencies for certain elements to concentrate in certain organs and in abnormal aggregations of cells such as tumors. Such behaviors make possible especially powerful methods of problem solving, including diagnoses of diseases and malfunctions. Several of these will now be considered in order to illustrate how international cooperation in the medical sciences, using the broad scope of atomic energy, can be of substantial aid to the health of humans, to reduction of infant death rate, and to the prolonging of lives beyond what is now considered to be a premature age for death.

Pertinent to essentially all potential uses of radioisotopes in medicine and appropriate at this point, is a consideration of the cost of equipping a hospital, a clinic, or a doctor's office. Calculations have been made and are given in some detail in Reference (1), showing that for a typical hospital laboratory program, the investment would be between $10,000 and $18,000. Further calculations of running costs suggest that income might exceed expenses by $2,300 annually if there are 30 or more cases per week. None of these costs include the fees of the physician himself. They also refer to patients who are paying their way, whereas in a program of international cooperation it is fairly obvious that many patients would be nearly destitute.

Blood-Volume Studies

One of the earliest available radioisotopes, P^{32} from the cyclotron, has been used for the measurement of both red cell and plasma volumes. For the latter there is a dye technique but it suffers from interference by liver fat as well as from hemoglobin escaping from destroyed red-blood cells in the liver. Since first demonstrating the validity of the method with P^{32}, Cr^{51}, which is more stable biologically, and radio-iodinated human serum albumin have been used with still better results. The red cells lose less than 1 per cent per day of the Cr^{51}, whereas they lose 6 per cent per hour of P^{32}. In addition, the Cr^{51} emits gammas which are more readily counted than the betas of P^{32}. For the tagging of red-blood cells, K^{42} and thorium B have been found to be applicable. In all of these cases of volume determinations, the classical dilution formula is utilized. These procedures have become quite valuable as laboratory aids in the measurement of numerous medical and surgical conditions.

Berlin, et al.[2], have made blood volume and hematocrit (red-cell concentration by centrifugation) measurements of a number of patients and covering several diseases. One anomaly that might not readily be observed otherwise appeared in the case of pulmonary tuberculosis. Blood volume was abnormally low. Hematocrit values appeared to be normal but plasma volumes had fallen to about the same extent as red cell volume. Thus the measurement of red-cell count by hematocrit alone would not have disclosed the deficient oxygen-carrying power of the blood in these cases of pneumonia. Sixteen of the 24 patients were candidates for thoracic surgery and would undoubtedly have suffered tremendously if the oxygen-carrying power of their blood had not been so carefully defined beforehand. In cirrhosis of the liver, plasma volume expands. This has led to the assumption by some that the comparatively low red-cell count (concentration) did not necessarily indicate anemia. Using radioisotopes rather than the formerly conventional dye method, it was found that the red-cell volume itself was low

in many cases of cirrhosis and so the patients were clearly anemic. There is a widespread belief that anemia is associated with advanced cancer. Only two studies of blood volume of patients with this affliction had been made prior to the work of Berlin, et al., who used isotopes. They sought an answer to the question of whether there was truly an anemia in terms of oxygen-carrying capacity rather than in terms of peripheral blood red-cell concentration. Covering the range of cancer of the pancreas, breast, lung, gastrointestinal tract, and miscellaneous areas, a high degree of inconstancy of anemia was found. Furthermore, at the time of the study, about the same fraction of the anemic group as of the nonanemic group had died. The availability of the radioisotopic method is helping, then, to place anemia in its proper perspective as a concomitant of cancer. In an extension of the cancer studies, these investigators included a number of patients with chronic leukemia. As in the case of cirrhosis, it was shown that a group would be reported as anemic because of low red-cell count, whereas the difficulty was really an abnormally high plasma volume. The patient suffering from chronic myelogenous leukemia could be identified almost absolutely by the combination of the hematocrit and red-cell volume levels. It is pointed out as a result of their work in conjunction with that of others that the true anemia of leukemia results in spite of a greater than normal red-cell production, coupled with a more-than-correspondingly shorter than normal life of the red cells. Thus these procedures for measuring red-cell volume and blood-plasma volume by means of radioisotopes have aided in diagnoses and have even given cause for decreased concern about symptoms, the significance of which previously had been improperly evaluated. They have also been used in veterinary practice where they have identified blood-volume norms, for example, showing that thoroughbred and Arabian horses average 11.0 ml of blood per hundred grams of body weight, while percherons average only 7.2 ml per hundred grams. Indications of anemia by these methods are also possible.

Dynamics of Water Metabolism and Changes in Total Body Water

Some of the commonest materials in nature are among the most difficult to measure quantitatively. Water is one of these. This is an aqueous world and the living matter in it invariably contains aqueous body and cellular fluids. Water is a distinctly inactive material at ambient temperatures, and therefore does not lend itself to easy or precise analytical measurement. A number of characteristics of the normal as well as the abnormal human body had been poorly defined until the advent of radioisotopes for medical use. Specifically we are speaking of tritium. In some few cases the non-radioactive but identifiable isotopes deuterium and O^{18} have been useful.

The total water content of the body can be determined by a standard tritium dilution technique. Considerable information on the composition of the body can be obtained by combining this with the density of the body measured by a novel helium dilution method which consists of placing the patient in a cabinet of known volume after which the unoccupied space of the cabinet is calculated by introducing a definite volume of helium and carrying out the necessary arithmetic. Add to this the measured extracellular water volume and the total body sodium, measured with the aid of Na^{24}, and it is possible to calculate body fat, water, and lean muscle mass. Prentice, et al. (3), determined that ascites (abnormal accumulation of water in the peritoneal cavity) involves a large and rapid interchange of water between the ascitic fluid and the blood plasma. I^{131}-labelled albumin made possible the measurements leading to this conclusion. A similar relationship was shown in cases of widespread cancer known as carcinomatosis. These findings are of potential usefulness in both diagnosis and therapy. It should be kept in mind that the dilution of tritiated water is a complex procedure. But much research has already gone into its definition leading to an adequate knowledge for diagnostic purposes. Abbott Radiochemicals is making I^{131}-4-iodoantipyrine, which is said to be suitable as a tracer for this determination.

Various spaces or compartments of the body are of particular interest in medical science. In some occasions there will be fairly rapid transfer of water or dissolved electrolytes from one compartment to another. In other cases, there is an apparent total or partial isolation. Radioisotopes have made it possible to measure the volumes of such compartments under both normal and abnormal conditions, thus adding to the power of the methods available to the diagnostician.

The normal human body is about two-thirds water. Body water, however, can neither literally nor figuratively be separated from its dissolved electrolytes. If, for example, one of the ions were invariably present in all parts of the body in the same concentration, it would be possible to use its radioisotope for total body-water measurements. This, however, is not the case. Accordingly, as mentioned above, an identifiable isotope of hydrogen or oxygen in water is necessary. It may be noted in passing that tritiated water may be generally thought of as THO rather than T_2O. There are many times, however, when it is necessary to know the volume of certain portions of the body fluid, for example, extracellular liquid. Sodium does not exist within the cell. Accordingly, Na^{24} is the logical isotope tracer for this purpose. When injected into man, the sodium ion distributes itself rapidly for 3 hours then more slowly for 6 to 9 hours, when equilibrium will have been reached. It is believed that the 3-hour distribution is through the extracellular fluid which, it has been found, normally amounts to about one-fourth of body weight. This has been referred to by Kaltreiter, et al. (4), as "sodium space" extracellular fluid. Fifteen per cent of this is plasma and 85 per cent is interstitial fluid. In pathological escapes of serum, the situation will be reflected by essentially identical sodium ion concentrations in pleural fluid, ascitic fluid, and blood serum. The extra fluid under such abnormal circumstances will be found in the extracellular fluid as determined by radio-sodium. Humans suffering severe burns show a substantial increase in "sodium space" extracellular fluid with a

simultaneous disappearance of sodium from the urine. This has been shown to be due to sodium withdrawal from normal equilibrium in extracellular fluid. In the course of the same studies, radioactive sodium was shown to be more highly concentrated within the burned area than elsewhere.

An interesting relationship has been found by the use of independent measurements with radio-sodium on the one hand, and deuterium on the other, when total body water and extracellular water of infants and adults are compared. It will be recalled that the adult body is about two-thirds water, while the corresponding figure for an infant is about 75 per cent. The extracellular water content of new-born infants, however, is 1.7 times as great as that of adults.

The mode of migration of sodium through the body has led to a method of locating the placenta. Radio-sodium was injected into 34 pregnancy cases. Since for the first few minutes Na^{24} confines itself mainly to the blood plasma, it would be found concentrated in a local accumulation of blood such as that in the placenta. In 31 of the 34 cases the defined area was confirmed by subsequent caesarean section or other means. A positive identification of placenta praevia is significant. A negative indication cannot yet be taken to exclude that situation.

From the examples given, it is considered to be evident that the behavior of water and the inevitably associated electrolytes in the body can be followed in many of the ways significant in diagnosis if fairly standard means of radioisotope utilization are known to the physicians involved. There are bound to be continuing discoveries of further areas of usefulness ranging from conditions of dehydration to edema and involving abnormalities of world-wide prevalence or of geographically localized significance. This is another field within diagnosis which may well constitute a part of an international cooperative effort in atomic energy through making the required isotopes available throughout the world as well as through the encouragement of research in this country and abroad.

Neutron-Activation Analysis

There are often medically important instances when exceedingly minute amounts of certain elements must be detected and their concentration determined at least approximately. For this, activation analysis has filled the need to a degree that microchemistry has been unable to do. Briefly, the principle consists of exposing the material to thermal neutrons, as in a reactor. Analysis of the induced radioactivity permits estimation of the quantity of the element.

It is usual to place the material in a reactor with a known weight of a compound of the element in question. Thus, if done carefully, both are subjected to the same neutron flux. After removal, following suitable neutron irradiation, a carrier is added to the unknown and isolation of the element is carried out by standard chemical means. Comparison of the radioactivity of the known and of the unknown gives the quantity of the element in the original material. Spencer, et al.[5], report that times of irradiation may range from 5 minutes to 1 hour. In unusual cases, a month may be required. The method may be considered to be nondestructive and is applicable to almost all types of biological specimens. Some otherwise extremely disagreeable materials may be handled in such a way as to avoid odors or contamination.

As a matter of fact, a reactor is not always necessary. Because of the low neutron flux intensities sometimes acceptable (2.5×10^8 neutrons/cm^2/sec or even less), Van de Graaff-beryllium, radium-beryllium, and antimony-beryllium sources can also be used. This illustrates the potential availability of the method to a considerable number of laboratories. Fabricated radium-beryllium sources providing a flux of 10^6 neutrons/cm^2/sec are available for only a few thousand dollars. Such a source containing one gram of radium will produce a flux of that magnitude at a distance of 1 cm. A 30-minute irradiation of a 10-ml blood sample would produce 800 gamma counts per minute from the sodium contained therein. A neutron-activation unit of this sort

presents the possibility of performing rapid sodium analyses around the clock with minimum effort and at fairly reasonable cost.

Lenihan and Smith[6] have described practical applications of activation analysis using as the example arsenic, the only stable isotope of which (As^{75}) has a large neutron-capture cross section, giving As^{76} with a half life of 27 hours yielding useful betas and gammas. In Great Britain, where their research was done, about 50 tissue samples, often of forensic interest, can be packed in a standard 30-ml container for shipment to Harwell for a 1-day irradiation. After air-mail return, the samples are assayed in a Geiger counter.

One of the applications described by Lenihan and Smith had to do with the possible absorption of more arsenic by smokers than by nonsmokers. Arsenic content of the hair was to be the measure. Among 1000 subjects, no significant difference was found between smokers and nonsmokers. The arsenic content of the hair of the men was found to be greater than that of the hair of the women. In a case of suspected arsenical poisoning, clippings of hair from the head, analyzed by the activation method, showed 65 ppm arsenic. Eighteen months later the patient assayed 0.89 ppm by the same method. Another patient habitually became ill after eating at home but not at the hospital. Two conventional analyses for arsenic were contradictory but neutron-activation analysis of the hair showed 0.77 ppm, which is well within normal limits.

The sensitivity of activation analysis is such that it will permit the determination of the following quantities, using simple apparatus and techniques.

Antimony	4×10^{-9} gram
Arsenic	2×10^{-9}
Copper	3×10^{-9}
Manganese	5×10^{-10}
Phosphorus	4×10^{-8}
Mercury	6×10^{-9}
Zinc	4×10^{-8}

W. W. Meinke[7] gives an extensive list of sensitivities based on irradiation in the Oak Ridge X-10 and Low Intensity Training reactors. For example, using the former, 3×10^{-9} gram of gold in 1 ml can be detected, an accomplishment of considerable value in cardiovascular studies.

Other applications of neutron-activation analysis include the demonstration of trace amounts of gold in the blood, measurement of iodine content of the thyroid, determination of the sodium and iodine contents of muscle and nerve material, and analysis of human tissues for cobalt, iron, and zinc. Rapid estimations of blood electrolyte levels can be made. It is estimated that the exposure of a 10-ml sample of serum to a neutron flux of 2.5×10^{8} neutrons/cm^2/sec for 1 hour will enable an investigator to obtain more than 30 disintegrations per minute from each of 15 different isotopes. At the opposite extreme, if sodium levels alone are desired, a scheme has been described for achieving such a measurement in 10 minutes. It is hoped that activation analysis will prove applicable to studies of cerebrospinal fluid.

Because of the comparative simplicity of this method, it is believed that it will find increasingly widespread use in medical research and diagnosis. Although for most general utility, a reactor is necessary at a location not far from the medical activity, it appears that much can be done even without a reactor. Highly skilled chemical and medical scientists are needed, however, and it is in this connection that the United States might well give consideration to an expanded program of international cooperation. Here, certainly, where so many of the radioisotopes produced are of quite short half life, the research or the diagnosis must be done where the patients are. Accordingly, personnel must be trained for work throughout the world, and neutron irradiation facilities, even though modest in cost, must be available in many locations.

Central and Peripheral Cardiac Disorders

The vascular blood flow of humans is an acutely vital process. A constant supply within rather well-defined limits of pressure, combined with a normal duty imposed on the heart as a pump, are important to health and vigor. Abnormalities may constitute illness in itself but when experienced in conjunction with disease can complicate the picture enormously. Peripheral requirements are satisfied by adaptation of the heart output through variations of pressure and of volumes of blood in the heart chambers. Pressure measurements are not difficult to make even if heart catheterization is necessary. The problem has been to measure volume content and volume flow rate.

The methods of blood-volume determinations within the heart have followed in general terms the method of estimating pool sizes in other parts of the body. It has been found that complete mixing occurs in the ventricles but not in the atrial cavities. These conditions result, of course, from turbulence in the first case and laminar flow in the second. It follows that the injection of a radioactive indicator into any of the four cavities of the heart should be followed by disappearance of the radioisotope at an exponential rate.

Some of the pioneer work in what later became known as radiocardiography was done by Prinzmetal, et al.(8), and by Waser and Hunsinger(9) in 1948. A compound of Na^{24} was injected into the vein of an arm and counts were made over the heart area. Six years later the method was used for calculating cardiac output, and several investigators have shown how to derive information on blood flow from the same data. There is now available a technique of selective quantitative radiocardiography to measure the rate of transfer of blood from one cavity to another. Intravenous injection of a radiotracer will enable it to flow rapidly into the right side of the heart. In a normal patient, changing the point of injection will not change the so-called right side of the cardiogram but may show substantial variation in patients with heart disease. Even in severe

congestive failure, however, injection into the jugular vein will give reproducible results. If the tracer material is radioiodinated human serum albumen (RIHSA) a complete radiocardiogram (RCG) will result. If the tracer is Au^{198} adsorbed on 30 to 50-micron carbon particles, it will be filtered out in the lung capillaries and a pure right curve will be obtained. The comparison of two such curves may be highly informative in cases of severe congestive failure with extreme reduction of right ventricular emptying.

To analyze left hemodynamics, radioiodinated methyl iodide (MI) can be inhaled. This avoids the prediluting effect of the right section of the heart if the tracer were injected intravenously. The main fraction of the detected methyl iodide is absorbed by the alveoli and is transferred rapidly to the left heart.

By combinations of the above three techniques, one can obtain quantitative data on (a) cardiac output, (b) rates of emptying of heart cavities, (c) blood content of heart cavities, and (d) traversal time through the cardiopulmonary system. These are important matters in medical research and diagnosis. It should be added, however, that the availability of radiocardiography has made possible the clarification of several problems of cardiopulmonary physiology. Briefly, some of these are that systolic emptying involves about one-fourth of cardiac blood content. The pulmonary vascular bed is not a mixing volume between the two sides of the heart. This appears to be true because blood flow in pulmonary circulation is laminar and mixing does not occur even though some dispersion does. A third revelation is that, in the blood's passage from the right ventricle to the left side of the heart, it resides during most of the time in the venous side of the pulmonary circulation.

The clinical applications of radiocardiography are numerous. A few examples are as follows. Several types of mitral disease can be identified and can be distinguished one from the other. These include mitral disease without regurgitation, regurgitation with stenosis, and pure stenosis. RCGs can also show right-heart

involvement in left-heart disease. Evaluation of the results of surgical therapy on the basis of improved hemodynamics can be made with the RCG before and after valvotomy.

Quite recently a considerable improvement over the MI-RCG has been developed utilizing Kr^{85}. This radioactive Kr has the advantage of a long physical half life and a short biological half life. Upon being inhaled, it reaches the heart more rapidly than can be shown by conventional recorders. Most of it is eliminated with a biological half life of 6 minutes. It does not concentrate in any organ. The Kr-RCGs cover four times as long a useful period as the MI-RCG. They have led to the rather startling conclusion that a diseased heart receives a greater fraction of its output as coronary flow than does a normal heart. This picture suggests that such a coronary insufficiency involves a diseased myocardium which must have an abnormally large fraction of heart output fed to it just to perform its basic function of maintaining adequate circulation. It is conceivable that this situation becomes increasingly aggravated until the heart fails. Such is the type of information which can be expected to result from further use of radioisotopes in medical research and diagnosis.

A serious congenital cardiac defect is a blood-flow shunt in the left-to-right flow which allows fully oxygenated blood to mix with the less saturated blood of the right heart. When Kr^{85} is inhaled, it appears very quickly in the arterial blood. Under normal conditions it appears in the right heart or venous blood only after one circulation. A left-to-right shunt causes Kr^{85} to appear in the right heart abnormally quickly and, thus, a rapid and reliable test for such shunts presents itself. In a group of 52 patients, the Kr^{85} tests had no diagnostic errors while the conventional oxygen tests had six.

It is possible now to measure coronary blood flow without catheterization of the coronary sinus. The newly described procedure utilizes rubidium-86, taking advantage of its chemical similarity to potassium. It is an important step forward to be able to measure blood flow in all of the coronary arteries at short intervals under normal

physiologic conditions. Radioisotopes and knowledge of their applications have made it possible and will undoubtedly permit extensions of the general method which, to the patient, is certainly "nondestructive" and to the physician is highly illuminating.

A knowledge of peripheral blood flow is important as certain disease states are characterized by defects in organ blood flow. Good starts have already been made but better methods and extended applications can undoubtedly lead to more precise diagnoses and even to prevention of some disease. As early as 1949, radioactive sodium was being used, with monitoring of the sole of the foot, to separate patients with arteriosclerotic and ischemic extremities from those having normal vascular supply. How far we have come in 11 years and an indication of what may lie ahead, given an adequate research effort, will be shown by the following examples of recent developments.

Blood flow to organs is now capable of being estimated quickly by a clearance procedure. Radioiodine-labelled diodrast (iodopyroacet) is excreted almost immediately upon arrival at the kidney in the blood. Similarly, S^{35}-labelled sulfabromphthalein is rapidly cleared by the liver.

Clues to the mode of production of cerebrospinal fluid are being sought by intravenous injections of radiosodium chloride using a patient having a complete block between the ventricles and the spinal subarachnoid space. It is suspected that the subarachnoid lining contributes, to some extent, to the production.

A clinical evaluation of intravenous injections of radioiodinated human serum albumen for detection of neoplastic liver disease has proved to be 96 per cent accurate.

The slow movement of tracer sodium into the brain leads to the reasonable inference that the blood-brain barrier is impermeable to sodium and what is present in the extracellular space of the brain arrives via the cerebrospinal fluid.

These are but a few illustrative examples.

It has been said earlier that one of the results of medical research and clinical activity of recent years has been to enable many more people to live longer. In evading

the diseases of childhood and middle age, these people will become increasingly subject to cardiovascular difficulties. Research must anticipate the approaching problems. Since their solution will benefit greatly from applications of principles of atomic energy, it appears to be desirable to consider this field in conjunction with a program of international cooperation.

Thyroid Function

The earliest extensive use of radioisotopes in medical research involved P^{32} and I^{131}. The literature of the latter extends to about 3000 papers and has expanded during recent years to some extent as a result of the availability of other radioactive isotopes of iodine with atomic weights from 124 to 135. As stated earlier, nearly 80 per cent of radioisotopic diagnoses are made with radioiodine. This is an indication not only of the extensively developed techniques but also of the demands for rapid, reliable, and sometimes difficult diagnoses for which the numerous methods so far developed are especially apt. Although RIHSA is admirably adapted to certain diagnostic applications not at all related to the thyroid, the more important medical characteristic of iodine is its strong absorption by the thyroid gland where it is fixed to protein molecules containing tyrosine groups.

Since the literature of thyroid diagnosis with radioiodine is so extensive, mention will be made of only the more important facts as they point toward further research which may be of world-wide interest. Just one fact attesting to such interest is that Drs. D. J. Rosenthal and John H. Lawrence have 18 visiting scientists from 12 different countries doing research in their section of the Donner Laboratory of the University of California at Berkeley.

At the present time, it is believed that direct measurement of radioactivity over the thyroid gland 24 hours after administration of the isotope is the most expeditious method for the appraisal of thyroid function. In 80 to 85 per cent of the cases, the true

status is thought to be reflected. A still higher degree of reliability is desirable, of course, and even now the use of protein-bound iodine is quite helpful. One of the confusing factors in thyroid function diagnosis is to distinguish between true thyroid disfunction and the effects of an abnormal pituitary. Since iodide is not only absorbed by the thyroid but, insofar as it is in excess, is excreted in the urine, practically all of the other 35 different radioiodine tests have dealt with measurement of the concentration of iodine in the urine at various time intervals. It should be noticed that British and American investigators independently have devised a procedure for measuring plasma clearance of I^{131} by the thyroid which does not require a knowledge of kidney function. A further departure from the more conventional thyroid function tests is an in vitro procedure which operates on an incubated blood sample. It will be obvious that in this case the patient is not exposed to the I^{131} radiation. All of these tests have reasonably high reliability for distinguishing between hyperthyroid and euthyroid individuals, but cannot separate the hypothyroid.

A knowledge of thyroxine secretion rate is often required. One of the newer and apparently well accepted methods resulting from recent research involves the coincident administration of thyroxine and determination of thyroidal release of I^{131}. The dosage of thyroxine is increased until no further loss of I^{131} occurs. This dosage then corresponds to the thyroxine secretion rate. It may be noted that one of the by-products of this medical research is a means of appraising the quality of domestic animal breeding stock for specific purposes such as milk production.

The isotope I^{131} has been by far of greatest importance medically. The fact cannot be ignored, however, that there are potential dangers in its use because of the tendency of iodine to concentrate in the thyroid. Especially when used for therapeutic purposes, it has been strongly suspected that cases of carcinoma resulted from it. Increasing attention is being given, therefore, to I^{132} with a half life of only 2.33 hours

rather than 8 days. With it, thyroid radiation is reduced by a factor of 30 and body radiation by a factor of at least 15. This isotope is especially useful with children and pregnant women.

With whatever isotope of iodine it should be realized that this element will only occasionally be of value in thyroid tumor diagnosis, particularly if the thyroid gland is still intact. Actually in the competition for iodine, the normal thyroid usually prevails over the diseased tissue.

In addition to the substantial although not completely developed contribution of radioiodine to the diagnosis of thyroid disfunction, there has been a valuable clarification of the pathological physiology. It has been explained through the use of different tracers how large doses of iodide can actually inhibit the formation of thyroxine, even though in hyperthyroidism the rate of secretion of the thyroid hormone into the blood stream is increased. Since the protein-bound iodine level in the blood is increased when this condition exists, its determination has become an important supplement to the basal metabolic rate in diagnosis.

Kao, et al. (10), have used I^{131} in their studies of endemic goiter in Formosa. In that country there are some areas where the problem is quite serious and where iodized salt has been supplied to the population. Their studies were made where the iodine supplement had not been supplied. The contribution of American research to this study is illustrated by the fact that the iodine was administered in the form of 25-microcurie Radiocap manufactured by Abbott Laboratories and the ORINS standard neck-phantom was used to obtain 100 per cent standard measurement. The results of the survey indicated that in these regions of Formosa the children exhibit more iodine hunger than the adults but also thyroidism develops at later ages than, for example, in the Boston, Massachusetts, area. Such findings can be of value, of course, in planning the therapeutic attack. It should be noted that at the time of Kao's report only I^{131}, P^{32}, and Co^{60} were being imported into Formosa. This example and others given earlier in this

section on medicine suggest what could be accomplished if a larger spectrum of radioisotopes were available along with the trained personnel to use them.

In Romania, Lupulescu, et al. (11,12), have found I^{131} and P^{32} to be of distinct value in their studies of the influence of various factors on thyroid function. They confirm the antagonism between the epiphysis and thyroid function. However, evidence is presented from unpublished work which suggests that the effect is more directly on the hypophysis which, of course, has a well-known stimulating effect on the thyroid when conditions are normal. They have found, further, that the administration of Vitamin B-1 causes hypofunction of the thyroid and that B-12 produces hyperfunction through the hypophyseal thyrotrope. Benzedrine stimulated thyroid function even more strongly than did Vitamin B-12.

Proper thyroid function, neither too active nor insufficiently active, is essential among many other factors for proper body function and activity control. Although prevalence of abnormalities will be found to be different in various parts of the world, hypothyroidism, for example, may be found in as varied locations as Switzerland, midwestern United States, and a spot only 40 miles south of Taipei, Formosa. Accordingly, to enable proper steps to be taken for treatment and to assure that those steps are the ones most appropriate for the region involved, it would appear to be highly advisable to supply the means for increased research and diagnosis both in quantity and quality wherever it is needed in the world. The consideration of this area in an international program of cooperation in atomic energy is indicated.

Malignancies and Benign Tumors

In both the professional and lay minds, radiation in medicine is generally associated first with the diagnosis and treatment of tumors. The contributions from numerous sources are enormous. Very recently, Chemical and Engineering News made a brief

announcement, as follows, of one of many such research developments under AEC auspices.

> "Preoperative diagnosis of body tumors by radioisotope scanning is now ready for routine clinical use, say research men at Oak Ridge National Laboratory. The new ORNL technique involves giving a radioactive pharmaceutical to a patient, then using a directional radiation counter to spot concentration of the tracers in abnormal tissues. Key feature: a gold collimator enclosed in a tungsten shield to pinpoint areas of high activity as the scanner moves in a definite pattern over the patient. The method was developed by J. E. Francis, Jr., and C. C. Harris, under the direction of P. R. Bell."

Although the radiation therapy of cancer is a complicated and rather highly developed subject, the use of radiation in the diagnosis of such abnormalities is much more restricted. It is confined substantially to the delineation of the borders of malignant tumors even in some extremely difficult locations.

Cerebral tumors, for example, have been identified and their extent has been defined by intravenous injection of radioisotopes followed by observation of the increased radioactivity at the tumor surface. The differentiation is not great but often is sufficient for the needs of the diagnostician or surgeon. I^{131}-labelled diiodofluorescein, sodium iodide, or human serum albumen may be used, as the occasion indicates. A recent development of the sort that may be hoped for in increasing numbers in future research involves the use of positron-emitting isotopes. As^{74} and Cu^{64} are examples. The positrons react with electrons in absorbing substances, each collision producing two gamma photons travelling in exactly the opposite direction. The increased contrast is a welcome improvement. During surgery when the skull is open, a beta emitter such as P^{32} can be used. A needle-like geiger counter then enables the surgeon to explore

the margins of the tumor and govern his excision accordingly. P^{32} has also been used for the precise location of tumors of the eye, particularly those of the melanomatous type.

At this point it might be advisable to say a few words about cancer distribution around the world. The Senate Committee on Government Operations published a report titled "Cancer: A Worldwide Menace" dated July 17, 1959. In it it shows that the highest rate of cancer mortality is in countries such as Finland, Austria, and Great Britain. However, most of the nations of highest standard of living are not far behind and, not surprisingly, the figures are not available for many of the underdeveloped nations. It is to be noted, however, that the occurrence of liver cancer is pronounced in Central Africa and in southern Asia, areas of monotonous diet and protein deficiency. As pointed out in an earlier section, Kwashiorkor is very general there in the infant and child population. Those who survive usually show fatty and fibrotic livers, a condition which has been correlated with the appearance of hepatitic carcinoma. It has been demonstrated almost certainly that an improved diet, especially one with adequate protein supplement, will prevent the liver damage and probably cancer. An expanded program of research to determine just what material is responsible for either causing or preventing the neoplasms would seem to be highly advisable and potentially rewarding. It would be applicable to populations totalling considerably more than that of the United States, and one whose standard of living is severely depressed.

Africa presents an unusually suitable location for a research team devoted to the pathogenic and histogenic relationship between liver cirrhosis and cancer. It is pertinent to the ultimate solution of the problem to know why immigrants to the United States from China, Japan, and the Philippines eventually show symptoms of primary liver cancer to a disproportionate extent. In much the same way, the Bantu workers in the South African gold mines who have excellent diets frequently give evidence of primary liver cancer which may be traceable back to their abysmally deficient diets in the bush.

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Their lung-cancer frequency, however, is believed to be much lower than (possibly one-fourth) that of Europeans. There is no doubt whatsoever that radioisotopes would play a large part in such a research campaign. Hopefully, the result in the not-too-distant future would be a scheme of therapy and perhaps some preventive steps which would reduce sharply the incidence of hepatic cancer among these currently susceptible people.

Further considerations of conditions leading to the appearance of cancer bring into the picture therapeutic radiation itself. There is much disagreement even among experts in the field as to the effect of X-ray treatments of the thymus on the subsequent appearance of thyroid cancer in children. One study of children less than 10 years old in England and Wales purports to show that there is a disproportionate incidence of malignancy in children whose mothers were examined radiographically during the relevant pregnancy. A subsequent independent analysis of the findings, however, casts doubt on the conclusions and questions whether the cause was the radiographic examination or the reasons for the examination in the first place. It was added that no case of leukemia was found after irradiation of the child or the mother with 1 to 2-1/2 r. An American study produced somewhat indeterminate results but provided a warning against indiscriminate use of radiation on children or infants for diagnosis or treatment of thymus abnormalty.

Therapy

Basic research can often be distinguished from applied research by the fact that its results are potentially useful anywhere in the world. The basic principles of Newton, Gibbs, and Einstein are not confined to the technologies of England, the United States, or Switzerland. Much of applied technology needs to be adapted to specific situations sometimes geographical in nature. In medicine this is not the case. Man is largely the same the world around although certain abnormalities may exist to varying degrees in various parts of the earth. A hypophysectomy or a treatment of

hyperthyroidism will be essentially the same in Syria, the Sudan, or Korea. The universal applicability of the radioisotopic treatment of certain ills and malfunctions of the human body are therefore of great practical and humanitarian value throughout the world. In many cases complicated and expensive apparatus is not necessary and so the methods are usable in underdeveloped countries and in remote regions.

The Thyroid

One of the elementary principles of photochemistry is that radiation must be absorbed to be effective in influencing chemical reactions. Not only must radiation of nuclear sorts be absorbed to be effective therapeutically, but an ingested radioisotope must be selectively absorbed or concentrated to influence a particular area such as the thyroid. It is for this reason, among others, that such a large fraction of the isotopes distributed for medical therapy will be found to be I^{131}. The element is strongly absorbed by the thyroid, the beta radiation penetrates only a few tenths of a millimeter of tissue, and the time of residence is such that it has decayed considerably when it leaves the gland in its protein-bound form. As a result, the beta-ray dose of the thyroid may be several hundred times that of the whole body.

In radioiodine therapy of thyroid disorders, it is advisable to consider thyrotoxicosis separately from cancer of the thyroid. In the former, where the avidity for iodine is tremendously increased over that observed in euthyroidism, the objective is to reduce thyroid activity by partial destruction (all but 1 to 2 grams). The dosimetry as well as the safety measures to be observed in disposing of the first 24 hours' urine are important. In spite of these hazards, responsible individuals can be treated as outpatients. As the method is extended to other parts of the world, particularly the underdeveloped nations, it would appear that key portions of the program would deal with (a) personnel training and (b) supplying the required compounds containing I^{131} and, perhaps in some cases, other isotopes of iodine. A successful treatment of this

sort leads to a clinical course similar to that after surgery or medication. It is doubtful that exophthalmic symptoms are reduced by radioiodine treatment. Where there are severe cardiac complications, thyroid surgery may be out of the question. In addition, thyroidectomy may be desirable to reduce the basal metabolic rate for the specific purpose of easing advanced cardiac disease including angina pectoris. For the rather rare cases of aberrant thyroid tissue (intrathoracic or intralingual) surgery may be difficult or dangerous. Destruction of this and the normally placed tissue by I^{131} may be preferable even though a subsequent thyroixine regimen will be necessary. Radioiodine treatment of thyrotoxicosis of children is usually avoided while for those between 20 and 40 years of age careful consideration is given before resorting to it. It is the treatment of choice for patients older than 40.

The first attempts (1940) to treat thyroid cancer with radioactive isotopes were unsuccessful. The residual capacity of the malignant cells to collect radioiodine was not sufficient to be effective and the remaining normal thyroid tissue could not collect iodine to the degree desired. Eight years later, however, it was found that after thyroid surgery, thiouracil therapy augmented the radioiodine-collecting power of the metastases, even to the extent of destroying them. So far, radioisotopic therapy of thyroid cancer should not be accepted with great enthusiasm. The rather large doses required are dangerous. Furthermore, not all of the comparatively limited number of thyroid cancer cases are amenable to such treatment. It may be estimated that the successful treatments are probably to be numbered in the dozens rather than in hundreds. It should be recognized, however, that cancer of the thyroid frequently represents a desperate condition calling for heroic measures probably involving both surgery and radiation.

In summary, surgery is usually preferred for thyroid-cancer patients unless it seems unlikely that all of the tumor tissue can be removed and except for highly anaplastic, i.e., undifferentiated tumors. If inoperable, then ablation should be

resorted to either surgically or, less desirably, by use of 80 mC of radioiodine. Actually, it is not easy to summarize the procedures to be recommended because of the numerous forms of thyroid carcinoma, degrees of differentiation, and condition of the patient. This situation, then, points up the need for still more research for the benefit of individuals throughout the world who are and will be suffering from this debilitating and sometimes fatal disease.

Nonthyroid Malignancies

Leukemia and Polycythemia Vera. Although these two diseases are not similar in their symptoms, they are both blood diseases and seem to be amenable to at least palliative treatment by radiation, particularly from P^{32}. When P^{32} is used as a source of radiation for body treatment, it must be recognized that although the malignant tissue utilizes more of the element than does the normal tissue, the uptake by bone is far greater and hence the danger of bone marrow suppression is a potential handicap to this method of therapy. A means of modifying the physiological process temporarily or the use of an entirely different radioactive element could be advantageous and thus suggests research, some of which, of course, is already under way. So far, P^{32} therapy is confined almost entirely to chronic leukemia and polycythemia vera. Although acute and subacute leukemia are not considered to be amenable to P^{32} therapy, one investigator has obtained rather good results with a combination of P^{32} and cortisone. The lymphatic type of chronic leukemia seems to respond best to phosphorus therapy. The group of patients studied at the Donner Laboratory of the University of California has a median survival time of 5.4 years, while that of the chronic myelogenous leukemia group have a median survival time of 3.2 years. The improvement in the former group is considered to be statistically valid. Another study of 2,000 cases reported in the literature over a 26-year period led to the conclusion that a significant prolongation of life could be expected. Radio colloids of chromic phosphate, yttrium, zirconium, and columbium

have been used for the treatment of leukemia as well as for polycythemia vera without significantly better results than those provided by P^{32}.

Polycythemia vera was first treated with P^{32} in 1939. At the Donner Laboratory, the average interval between treatments is 33 months, which is considerably longer than that experienced in conventional nonradioactive therapy of the disease. The median survival time is 13.4 years as compared with 6.7 years for those treated by conventional methods. The extension of the life span through P^{32} treatment of this disease is very similar to that experienced in liver treatment of pernicious anemia and insulin treatment of diabetes. The dose, either intravenously or by mouth, is from 3 to 5 mC, depending upon the weight of the patient. Retreatment may occur in 4 or 8 weeks, if necessary. After satisfactory control has been attained, further retreatment is rarely necessary before 1 to 3 years. In one group which has been reported on, most of the cases demonstrated a red-count decrease from 7.25 million to between 4 and 5 million with a substantial relief of the disturbing symptoms. In about 20 per cent of the individuals treated, there were complications in the form of leukopenia, thrombacytopenia, or anemia because of the effect on the bone marrow. There may be a slight incidence of leukemia which would not otherwise be experienced. The very attractive increase in longevity, however, recommends the method for polycythemia vera in spite of the danger of complications. This will hold until a better treatment is developed. Present indications point to increasing incidence of the various malignancies in the foreseeable future both in this country and abroad. Constant improvements in therapy, radioactive and otherwise, will be developed in the course of chemical and medical research. Making some of this part of an international program of cooperation in atomic energy appears to deserve careful consideration.

Neoplastic Diseases. Among the numerous forms of malignant tumors there is a great variation between the sexes and among ethnic groups, both those living together

and those in their own homeland. Thus stomach cancer is decreasing as a cause of death, because of decreased incidence, in the United States. Especially high stomach-cancer mortality rates exist in Japan however, generally so in the higher latitudes and less so in the tropics, as in Latin America. Lung involvement is now the leading cause of cancer death for millions in the United States, but the increase from this type seems to be even greater in England and Wales. Chances of survival remain very poor in spite of improved surgical techniques. Excessive risks appear to be associated with cigarette smoking, urban residence, and certain occupations. Among females in this country the breast is the main site of cancer and this situation has not changed particularly during the last generation. Strikingly lower incidence occurs in Japan and southeast Asia. Uterine cancer incidence has not changed much in this country but the death rate from it has been declining. Strangely, an area with high breast-cancer mortality has a low uterine-cancer mortality and, on the contrary, the low breast-cancer mortality of Japan is associated with an unusually high death rate due to uterine cancer. It should be noted that the epidemiology of cervical cancer is quite different from that of cancer of the uterus. As has been pointed out earlier, cancer of the liver and the biliary tract is especially frequent and serious in Asia, Africa, and Malaya. In the United States its importance is decreasing. These instances of variability in prevalence of different types of cancer depending on geographical area are important to any international program of research on the use of radiation in combating them. Obviously it is not solely a matter of geography but one of diet, level of nutrition, parasitism, micro- and macro-pollution of the air, and national habits. In any case, as has also been pointed out before, it is the particularly frequent and fatal type of cancer that is of the greatest importance to a region under consideration whether Japan, Ghana, Chile, or the United States.

Insofar as radiation is a palliative, a life-span extender, or a cure in such disease, it is clear that the research directed toward its most effective use

therapeutically must be designed to meet the precise conditions in each nation or region within the nation.

Because of the complex nature of the therapy of neoplasms, only a few examples will be mentioned here. It is felt sure, however, that they will show how much remains to be done for the benefit of all humans. First, let it be said that radiation cannot be considered as a treatment apart from surgery and chemotherapy. All may be used together or any two of them and, less frequently, radiation might be used alone. In one area which was studied, surgery was used almost exclusively for cancer of the large intestine, while radiation was by far the most frequent method for cancer of the cervix. Cancers of the oral cavity on the other hand were treated by surgery or radiation to about equal extents.

Multiple myeloma has been treated with I^{131} both as iodide or as RIHSA. Considerable relief of pain was obtained and there were relapses of 3 to 4 months for which retreatment was effective. The anemia was not improved. In malignant metastatic melanoma, radioiodine produced no favorable change. Radiocolloids have been used for a number of types of malignancies intravenously, by injection into the tumor, and by instillation into the cavities. Radiogold colloids intraperitoneally have benefited 50 to 75 per cent of a group of patients suffering from malignant effusions. There is no evidence yet that life expectancy is prolonged. It is to be noted that in this type of treatment radiation sickness is absent or slight.

Many groups employ routine peritoneal application of colloidal radiogold in all cases of ovarian cancer. Even though the surgical removal may have appeared to be complete, there is the possibility of microscopic tumor implants, especially if there has been a rupture of a cystic ovarian carcinoma. The radiogold is expected to destroy these free-floating cells. Thus, it will be recalled, is somewhat analogous to the use of nitrogen mustard in malignant-tumor surgery. In a series of 51 patients with

ovarian cancer, survival rates were such as to suggest strongly that true progress had been made by this means.

More than 10 years ago, radiogold colloids were administered interstitially. There are disadvantages here because of the difficulty of obtaining uniform distribution in the tumor and the danger of encountering a vein which transports the radiogold to undesired locations. Colloidal chromic phosphate has produced results similar to those obtained with gold and with the advantage of a longer half life as well as less danger, because of absence of gamma radiation.

Another application of radiogold has been in cervical carcinoma, not by direct injection into the primary lesion, but by radiating the lymphatics and the lymph nodes.

In inoperable bladder cancer, Na^{24}, Br^{82}, and Co^{60} have been administered in the form of a fluid contained in a balloon. More recently Co^{60} and Ta^{182} have been used in a form of wire, needles, or pearls, and have been advocated as an improvement over radium. Co^{60} is of special value because it can be machined to various shapes. Ta^{182} wire has proved useful for irradiation of the tumor bed following brain surgery. For the treatment of uterine hemorrhages in the menopause, it was desired to find a beta emitter with good tissue penetration but without the ability to irradiate the ovaries or deeply into the muscular tissue. Y^{90}, a pure beta emitter seems to fit these requirements and appears to have been successful in stopping uterine bleeding. This same isotope, in the form of yttrium chloride, has only been moderately satisfactory for the treatment of carcinoma of the prostate.

Still in a very preliminary stage is an attempt to treat advanced metastatic cancer by destruction of the hypophysis through the implantation of Y^{90} or Au^{198}. So far it appears that the whole pituitary does not receive enough radiation to produce complete loss of function. With the knowledge that about half of carcinomas such as those of the mammary gland depend on pituitary hormones for their growth, radiation hypophysectomy was performed with 340-million-volt protons on patients with advanced

metastatic carcinoma of the breast. A dose of 26,000 rad over a 3-week period gave evidence of complete hypophysectomy in 3 months. The patients who were all in an advanced, sometimes near-terminal state, had had access to all other available forms of therapy. About half of them experienced end results which could be termed beneficial. Improvement took place and lasted from a few months to 3 years. This seems to be a powerful method for precise irradiation of small volumes difficult for surgery but requiring fairly large doses for destruction of function.

Needless to say the eye is one of the most delicate areas in which to carry out procedures designed to alleviate malignancies. Fortunately the radioisotopes which are pure beta emitters provide a means for supplying radiation to limited tissue depth, thus confining treatment essentially to the surface if that is the affected region. If it were not for this characteristic of beta radiation, it would be extremely difficult to avoid damaging the lens of the eye. Naturally the beta emitter, whether P^{32}, Sr^{90}, or Y^{90}, can usually be formed into the desired shape, as for example to fit the surface of the eye snugly. As might be expected, P^{32} was the first one used. More recently Sr^{90} foil has been produced at Amersham, England. The so-called shell is not only useful for applying the foil but also shields the operator himself from radiation. Since there is a thin plastic layer between the foil and the eye, the low-energy beta radiation of Sr^{90} does not escape at all and only the 2.3-Mev betas of the daughter yttrium are therapeutic; the strontium having a half life of 28 years makes it unnecessary for renewal of the active material in the shell. This treatment has been used for corneal ulceration and vascularization, malignant melanoma of the corneal limbus, as well as rosacea and certain forms of keratitis.

More research will be done in the radiation therapy of cancer in its many forms. It is logical that the research of each country so far has dealt mainly with the problems characteristic to itself. A research program of international cooperation would give increased attention to the problems of other parts of the world without neglecting the

many domestic ones that remain. In the previously referred to Senate Committee Report on "Cancer: A Worldwide Menace", the most important elements of an integrated program of cancer research were listed as:

(1) The training of research personnel

(2) Better communication among cancer research workers, through international symposia, exchange of scientists, etc.

(3) The development of uniform definitions, standards, and nomenclature for measuring and reporting results of treatment

(4) Planning of research programs, using talents available anywhere in the world

(5) Financial aid to medical research.

For such a program on radiation, the third element must be considered of least importance and the need for radioisotopes, X-ray equipment, and accelerators might be mentioned specifically.

Reactors, Accelerators, and Activation Therapy

In using radioisotopes, especially by administration to the patient, one must observe not only the chemical implications upon ingestion, but also the matter of the radiation itself. In the case of needle implants, of course, chemistry is not involved except as corrosion occurs. If, now, an innocuous stable isotope could be placed in the area to be treated, and then could be bombarded with the neutrons of a reactor, then it might be possible to get an unusually heavy ionization with the consequent destruction which is needed in cancer treatments. Accordingly, the Brookhaven National Laboratory has had operating for about a year a Medical Reactor which supplies a neutron beam for the treatment of brain-tumor cases. Although the choice of stable elements to be concentrated in such an area is small, one of them, B^{10}, has a suitably large thermal-neutron-capture cross section and subsequent rapid disintegration into

energetic particles. Each neutron capture produces one alpha particle and one lithium particle with the release of 2.4 Mev of energy. This method of treatment has been used mainly on glioblastoma multiforme. Besides the reactor at Brookhaven, Massachusetts General Hospital is planning to use the medical port of the reactor at MIT.

Accelerators provide a flexible source of radiation in that their electron or positive-ion beams can be adjusted to provide the desired depth of penetration. Accelerators produce their radiation in narrow beams which can be aimed precisely at localized tumors and metastases. The 70-Mev synchrontron at the University of California School of Medicine is one of these. The Argonne Cancer Research Hospital now has a 50-Mev linear accelerator equipped with a scanner so that this narrow collimated beam will cover an area of skin in much the same way that a television picture is formed. As a final example, the hypophysectomies with 340-Mev protons were described above as practiced for the treatment of advanced metastatic carcinoma of the breast.

Accelerators and reactors present a rather special case for consideration in an international program of cooperation in atomic energy, in that they are unusually expensive pieces of apparatus. As they exist in this country they constitute instructional devices for visiting scientists of many nationalities. They may even be highly practical for the treatment of patients transported some thousands of miles to them. The number which are being built in other countries will probably be comparatively few. It remains, however, that there are no questions of short half life or even of using potentially dangerous radioisotopes in primitive places. If installed in countries which are not advanced scientifically, it is to be expected that the associated laboratories and their apparatus will also be installed and the clinics in their entirety will be properly staffed with trained personnel. These sources of radiation must certainly be thought of

in world-wide medical research but they must be given their proper place both as extremely important instruments and as inevitable rarities.

Teletherapy

Teletherapy is the method of treatment usually involving massive doses of radiation from a source at a distance. For some years X-rays have been used for the purpose and are often thought of in two groups, i.e., the 250-kv and the million-volt generators. More recently Co^{60} has been used, having as one advantage, of course, the absence of a continuous power source. Its decay rate of about 1.1 per cent per month makes it unnecessary to replace the original inventory of cobalt more frequently than every several years. The beta radiation is easily filtered out. The two gammas are of 1.17 and 1.33 Mev, thus simulating million-volt X-rays. The customary source-to-subject distance is 50 to 100 cm and the nearest point of the collimator must be at least 15 cm from the subject to avoid interference from secondary electrons. The maximum ionization within the subject is at a depth of 6 mm, thus sparing the skin including the sensitive layer 2 to 3 mm below the surface from unnecessary radiation. For a given dose in a tumor, the total energy absorbed by the body is less by a factor of 2 or 3 than that from 250-kv X-rays. Bones do not interfere, since their absorption is no higher than that of soft tissues. Thus the usefulness of Co^{60} teletherapy is based on the absence of skin reaction, lack of bone and cartilage involvement, and better systemic tolerance. The method is especially suitable for deep-seated tumors or tumors adjacent to bone and cartilage. Certain carcinomas of the paranasal sinuses, tonsils, tongue, and parts of the pharynx are suited to such treatment providing they cannot be readily handled by interstitial injection. Tumors of the abdominal cavity are especially appropriate subjects for teletherapy. Advanced carcinomas of the cervix, the uterus, and the bladder sometimes are more easily treated by teletherapy than by intracavitary means, although at times both may be used. A word of warning has been issued,

however, that with both million-volt and neutron therapy the complicating consequences should be estimated as carefully as possible in advance since severe sequellae are believed to have developed years after such treatment.

Teletherapy is almost like neutron-activation therapy in presenting a rather complicated and expensive apparatus picture to those who are to use it in remote parts of the world. Teletherapy in its present form and in the forms which will develop as a result of the research in the coming years, is bound to be a potent force in the treatment of malignancies experienced in all parts of the world. Accordingly, research on new types of apparatus and isotopes other than Co^{60} will be a subject worthy of substantial support. The benefits will be international; the support should be with the international welfare in mind.

Opportunities for International Cooperation on the Medical Applications of Atomic Energy

Man, as the world's most widely dispersed animal species, is subject to some ills which are ubiquitous as well as to some that are unique to a race or to an area. Of all the animals of the world, man has gone farthest in the mastery of his own fate, medical science probably being the outstanding manifestation. The applications of atomic energy to medical diagnosis and therapy have been many and they have been valuable. There is little doubt that their variety and their importance to man will increase rapidly as a result of the research done and the research that will be done during the next few years. The medical needs of an underdeveloped country are fully as great as those of the countries at a high stage of development. Accordingly, a nation such as the United States which has advanced far in atomic energy and in medicine may well give serious consideration to an expanded program of international cooperation in this area. Health, vitality, and extended life span are economic as well as humane

benefits. To achieve them on a more nearly worldwide basis, contributions from atomic energy may well be augmented by some or all of the following steps:

(1) Basic medical research cannot be separated so precisely from applied research as in the case of other disciplines even including agriculture. Basic medical research is too closely identified with diagnosis to do this. As a result, then, research in diagnostic procedures must continue and may well be stimulated in other nations at the instance of this country.

(a) The diagnosis of cardiovascular ailments is aided materially by knowledge of blood volumes. The methods which have been worked out so far using radioisotopes have been useful. Still further improved methods are needed which will not only give blood volume but also unambiguous information on the presence or absence of anemia. It will be characteristic of the examples given in this summary that the assistance by the United States may partly be in the form of personnel training, isotope supplies, and equipment gifts or loans. This will enable the needed research to be continued here and, additionally, to be started or expanded in other countries.

(b) Nondestructive measurements of certain spaces in the body as well as of water content are important diagnostic procedures in a number of different types of disease. It is advisable for physicians throughout the world to be trained in the methods which involve radiation in order that the information may be available to them for any of a number of diseases, some of which may be endemic where they are.

(c) Although of limited application so far, neutron activation analysis appears to have potentialities which should be exploited for diagnostic purposes. In such cases the equipment will not need to be nearly so expensive as it would be for therapy. The special requirements of other regions of the world may well bring out additional applications for this method of analysis.

(d) Cardiovascular disease is of increasing concern in this and some other countries with a high standard of living. As the standard increases elsewhere in the

world, and as the life span becomes longer, it seems quite possible that the prevalence and seriousness of these circulatory disorders will require still further attention. Here, as in all of the other listed opportunities, it is recommended that the philosophy be one of putting medical science into an advanced position even in the underdeveloped countries without forcing it to go through the various stages that it has gone through in the United States. Radiocardiograms, then, should be adoptable quickly by diagnosticians in all parts of the world.

(e) Thyroid disfunction, except as it is brought on by a malfunctioning pituitary or by malignancy, will undoubtedly continue to be a phenomenon most prevalent in rather small areas widely distributed throughout the world. As it affects vitality and even health it deserves continued attention much of which can be through radioisotopes.

(f) Although, as will be indicated later, radiation is of value in tumor removal, surgery will most certainly continue to be important. In any case, the delineation of the tumorous growth will need to be accomplished and with greater and greater precision. Much additional research is needed both here and abroad to give improved methods from the standpoint of speed and exactness, the latter particularly to provide a greater differentiation between therapeutic radiation of the abnormal and normal tissues.

(2) If disease cannot be prevented, every effort must be made to cure it. Radiation therapy has assumed a place of importance already. It is bound to go further and further. As in diagnostic procedures, medical scientists from every part of the world must be trained in the best methods. They must be supplied with the best apparatus and with the appropriate radioisotopes. The universality of therapeutic methods including, of course, radiation, makes clear the contribution that a program of international cooperation can make to the world's people. Examples follow and all imply the training of men and supplying of materials.

(a) Radiation treatment of cancer may almost be dismissed by simply listing it. The large number of forms of the disease and the versatility of the methods are

so well known that extensive description is really unnecessary. Let it be said, however, that the extremely small percentage of cures and the very small percentage of life-span extensions beyond more than a very few months point up the stupendous amount of research which remains. No group of the world's population is free of cancer. The therapeutic means are needed for all. Surgery, radiation, and chemotherapy are all contributors. This country is in an excellent position to give assistance in all three fields. With the additional observation that this applies to neoplastic cancer as well as to leukemia and polycythemia vera, no more needs to be said.

(b) The therapeutic use of radiation for nonmalignant problems other than benign tumors is extremely rare. An example was the destruction of the hypophysis for the purpose of alleviating cardiac disorders. It is believed that there may be other such applications and it is suggested that an international program of cooperation in research on atomic energy in medicine give consideration to other such therapeutic applications.

A characteristic of true research is its inability to predict results, especially new discoveries. Another characteristic is that research will present new problems as well as solve current ones. It appears, then, on the basis of the accomplishments of the past in radiation diagnosis and radiotherapeutic research, that extremely important advances will be made in the foreseeable future. Medically it is undoubtedly a truism that what is good for our own country is good for the rest of the world. Additional research programs on radiation in medicine would be expected to provide additional benefits.

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LETTER REQUEST TO ATOMIC ENERGY COMMISSION

This will confirm our discussion * * * concerning the preparation by the Commission of a Report on the International Status and Prospects for Atomic Applications other than for Central Station Electric Power.

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TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

* * * I enclose * * * two reports prepared by the Commission's Division of Reactor Development:

Industrial Applications of Nuclear Reactors other than for Central-Station Generation of Electricity

Status of Merchant Ship Nuclear Propulsion Program in Various Countries

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INDUSTRIAL APPLICATIONS OF NUCLEAR REACTORS OTHER THAN FOR CENTRAL-STATION GENERATION OF ELECTRICITY

The McKinney Panel report of January 1956 included information concerning high temperature process heat and space heat. Since that time, the AEC has continued its study of such applications, and has restudied the energy utilization market, in light of the progress in technology to more accurately assess the potential of nuclear reactors for heat applications. The AEC's interest in non-power heat utilization covers three temperature ranges, intermediate-, high-, and low-temperatures. Intermediate-temperature process heat is defined as heat in the temperature range which can be produced by reactors being developed for the utility industry; temperatures above that range are considered "high", while those below are "low".

Developments in High-Temperature Process Heat

In January 1956 it was believed that nuclear energy offered promise as a source of high-temperature heat, since the energy resulting from the fission process could be released at temperatures higher than those available from fossil fuels. Many processes, such as the Wisconsin process for fixing nitrogen, the Wulff process for producing acetylene, the production of hydrocyanic acid from methane and ammonia, metallurgical processes, and coal gasification, were proposed as possible applications. Since that time, both the AEC and industry have continued their studies and have concluded that building reactors for such processes is not now technically feasible and would require a sizeable research and development program. Industry has discontinued research and development directed at such applications. The AEC has concentrated on developing fuel elements which retain fission products and on development of reactor components for a high temperature reactor system. The fuel element work is being carried out on graphite fuel elements under the fuel cycle development program and in a small reactor experiment being built at Los Alamos. The component development work is being performed under a joint effort, with the Bureau of Mines. Since the feasibility of building a reactor for high-temperature applications is questionable, the emphasis now being placed upon it is necessarily limited.

Developments in Intermediate-Temperature Process Heat

The AEC has not placed any special emphasis on developing process heat reactors for this temperature range. By the above categorization, process heat reactors for application in this temperature range are identical to those for supplying heat for the generation of electricity. The mere application of these reactors to producing the same type of heat for the processing industry is not a research or development problem and the process industries will be able to adopt them as soon as they become economically competitive.

Developments in Low-Temperature Process Heat

The AEC has performed several investigations in the low-temperature process heat area. The market has been surveyed to ascertain the economic structure and areas of potential application. Reactor feasibility studies have been performed and ground breaking for the construction of an experimental low-temperature process heat reactor is planned for the spring of 1960.

It should be noted that space and low-temperature process heat fall into the same temperature range. Space heat is that used for supplying building comfort. Process heat is that used to convert raw materials into other products. While both fall into the same temperature range, units supplying process heat are applicable in industry, while units supplying space heat are of primary interest to municipalities and organizations operating large institutions such as hospitals, colleges, etc.

Space Heat

Studies concerned with the economic feasibility of building reactors for space heat, both from the military and civilian viewpoint, have been made by the AEC. While the studies of military applications have shown nuclear reactors to offer some promise in remote areas, these areas also require power. Thus, they require the use of an intermediate-temperature range reactor in which the higher temperature heat is used for producing electricity and the heat rejected by the power turbine is used for space heating. Investigations for use in civilian applications have shown reactors to be uneconomical because of the small size of the installed unit and load factors. The load factor of space heat boilers varies between 20 and 35 per cent, making it difficult to justify the higher capital cost of a nuclear installation. In view of the lack of economic promise for such applications, the AEC has no immediate plans for specific work in the field of civilian space heating. Data from the military reactor program relating to such application is available, however.

Process Heat

In 1957, the AEC performed market surveys of heat utilization in the United States. These studies showed several interesting facts concerning the low-temperature process heat reactor field. First, they showed that approximately twice as much fossil fuel is used to produce low-temperature process heat as is used to produce electricity. Second, while this amount of fossil fuel is quite large, it is consumed in relatively small blocks, 96 per cent of the installed units being less than 75 thermal megawatts with the medium-sized unit being 10 thermal megawatts. Third, of the process industry's total manufacturing cost, only 3 to 6 per cent is attributable

to fuel. Fourth, the cost of heat used by some individual companies amounts to as much as $1 per million Btu. Fifth, because the process heat industry's expenditure for raw material amounts to from 5-10 times their expenditure for fuel, they will generally locate closer to sources of raw material than to fuel. While these last two facts lead to the conclusion that the competition nuclear reactors would experience from fuel costs in process industry would not be as severe as in the utility industry, other offsetting factors were revealed. The capital cost of nuclear process heat units is undoubtedly higher than that of fossil fuel units.

The Argonne National Laboratory reported the results of its study in June 1959. Its estimate of the cost of steam from three reactor types is shown in Table I.

TABLE I

Reactor Type	Pressurized Water		Organic Moderated	Boiling Water
Steel in Primary System	carbon	stainless	carbon	stainless
Fuel Cladding	zirconium	zirconium	aluminum	zirconium
Charges, ¢/1000 lbs. of steam				
Capital*	38	42	34	34
Operating	15	15	21	15
Fuel	20	20	24	28
Inventory @ 4%	12	12	17	32
Total	85	89	96	109

*at 15% per year fixed charges and 90% load factor

While the above figures show that pressurized water reactors have the lowest cost, it is felt that the organic and boiling water reactors still have a competitive place in the field when their specific advantages are warranted, i.e., the organic reactor is capable of producing higher temperature steam at essentially no increase in cost. The boiling water reactor is probably more economical in larger sizes.

After evaluating these studies, the AEC requested Congressional authorization to build an experimental process heat reactor for a two-fold purpose: 1. to demonstrate the capital cost of a 40 thermal megawatt pressurized water reactor constructed with a low alloy steel primary system; 2. to embody features which would lead to cost reductions in future low-temperature process heat reactors. At about the same time, the Department of Interior approached the Commission on the possibility of supplying a nuclear reactor for a flash evaporation sea water distillation plant. A cooperative arrangement was entered into in the fall of 1959, which provides that the reactor be adjacent to the Interior's sea water distillation plant to supply 15 thermal megawatts of 15 pound per square inch steam to the flash evaporator. It should be emphasized that while this reactor will supply steam to the sea water distillation plant, its objectives are oriented toward the application of a nuclear reactor in the industrial process heat industry, rather than to demonstrate the use of reactors for desalinization of ocean water.

Congressional authorization for the low-temperature process heat reactor was obtained for FY-1960. An architect-engineer and reactor manufacturer have been selected and design work is well underway. Construction at the site will be started this spring and it is expected that the reactor will be in operation in 1962.

Nuclear Energy and Desalinization of Brackish or Ocean Waters*

The AEC and the Fluor Corporation have investigated the possibility of dual purpose nuclear reactors for the production of electric energy as well as for desalinization of water. The consequences which result from the coupling of a power plant to a water plant tend to make such a combination less economical than a cursory examination would suggest. Difficulties arise because the economical generation of either product (fresh water or electricity) depends upon the simultaneous generation of the other, and the ratio of the total water consumption to the total electrical energy consumption very rarely coincides with the optimum production ratio.

This production difficulty would not exist if the electrical energy could be stored in the sense that water can be stored, but since it cannot, and the simultaneous production of water and electricity is essential to the economics of the integrated plant, it follows that the load factor of both the water and electrical plant will be dictated by the demand for the non-storable product, electrical energy. In the calculation of water costs, it is customary to use a load factor of about 90%, whereas the average load factor for a modern electric production plant is only about 60%. This mismatch in load factor results in a 50% increase in all costs except fuel for the water plant. Of course, it is possible in certain locations to integrate the electric power plant with an electrical distribution system large enough so that the minimum demand on the system exceeds the output of the power plant. In this case, a load factor of near 90% could be obtained. The effect of this, however, is to reduce the overall system value of the electricity or increase the cost of the exhaust steam.

The AEC has also investigated the use of a nuclear reactor specifically designed for the production of low temperature and pressure steam which can be used for the evaporation of sea water. It is concluded that while this application is interesting and shows promise in the long range future, the success of such an application depends largely upon developing an economical evaporator. The development of such an evaporator is clearly within the functions and responsibilities of the Office of Saline Water of the Department of Interior. At this time, the Office of Saline Water is necessarily vague in their estimates of the potential use or need for such a reactor. This vagueness is due to the uncertainty in their predicted future costs and in the expected results of their current demonstration program.

The Office of Saline Water's demonstration program provides for the construction and operation of five one-million gallon per day water plants

*Excerpt from report by USAEC to the Select Committee on Water Resources of the U. S. Senate, entitled Effects of Nuclear Energy on Water Use and Supply, January 1960

to determine the engineering feasibility and economics of large scale water production. The AEC is cooperating with them on one of these plants by the construction of its Experimental Low-temperature Process Heat Reactor authorized for FY 1960 at the site of the Office of Saline Water's West Coast Sea Water Distillation Plant at Point Loma, San Diego, California. In order to determine the cost of producing water from a large scale nuclear powered sea water distillation plant, the Office of Saline Water contracted with the Fluor Corporation to perform a technical and economical evaluation of such a plant. The AEC cooperated with Fluor in preparing the final report entitled "Preliminary Design Study of an Optimum Nuclear Reactor - Saline Water Evaporator Process" dated August 1959. The results presented in the report are:

> The cost of potable water produced from sea water in a fifty million gallon per day 52 stage flash evaporator, when steam is supplied by a 370 thermal megawatt pressurized water reactor is estimated to be 42¢ per thousand gallons. This water cost includes all costs associated with the operation of the plant. The cost of steam from the nuclear reactor is estimated to be 37¢ per million Btu in the form of steam when all nuclear fuel costs, as well as capital and operating costs, are included.

The AEC staff has estimated the cost of potable water from the largest reactor which could be constructed today for water production. The reactor would be moderated by graphite and cooled by light water and would produce approximately 3000 thermal megawatts. The technology for this reactor type is well established and the reactor could be built with little or no research and development. The estimated cost of steam from this reactor is 28¢ per million Btu. Assuming that an evaporator operating cost of 19¢ per 1000 gallons can be attained, the water production cost will be 36¢ per 1000 gallons.

During discussions between the staffs of the Select Committee on Water Resources of the U. S. Senate and the AEC, an earlier preliminary analysis by Mr. R. Phillip Hammond of the University of California was mentioned. This paper was printed in the January 1956 "Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy". In this analysis, it was estimated that it might be possible to construct a nuclear powered desalinization plant which would produce one billion gallons of fresh water per day for 10 to 15¢ per 1000 gallons. The reactor type employed in this analysis was a boiling heavy water slurry reactor. In order to produce one billion gallons of water per day (which is twice the present requirement of the City of Los Angeles), the reactor would have to be capable of a heat output of 10,400 megawatts. A boiling heavy water slurry reactor (of any size) is not within the limits of present technology. At present, the only operating reactor approaching this type is the Homogeneous Reactor Experiment-2 at Oak Ridge National Laboratory. This reactor experiment uses a uranyl sulfate solution in pressurized non-boiling heavy water. The Westinghouse Electric Corporation performed some

studies on the use of a slurry in a non-boiling heavy water reactor, but they have discontinued their work. Some work is presently being done at Oak Ridge National Laboratory on slurries in non-boiling heavy water systems. Therefore, the present technical data on slurries in heavy water is quite limited; the data on slurries in boiling heavy water is even more meager.

The AEC Fluid Fuel Reactors Task Force in their February 1959 report to the Division of Reactor Development stated that to demonstrate the feasibility of a pressurized non-boiling heavy water slurry reactor as a commercial power plant would require in excess of ten years and 100 million dollars. A program to demonstrate the feasibility of boiling heavy water slurry reactors would undoubtedly require even more time and money.

Because the technical data on boiling heavy water slurries are so meager, it is not meaningful to assign power production costs to such a reactor. The 10 to 15¢ per thousand gallon figure which Mr. Hammond presented seems particularly unfounded compared to the 3000 megawatt AEC water production plant figure of 36¢ per thousand gallons. The Fluor conceptual evaporator plant above requires 19¢ per thousand gallons for its operation.

The construction and operation of the Experimental Low-temperature Process Heat Reactor (ELPHR) previously mentioned will provide an experimental facility specifically designed for the production of process heat. Additional basic supporting research on this reactor application will be necessary and will undoubtedly be done at one of the AEC's national laboratories. The amount of research is expected to be quite small because of the wealth of information already available from the Commission's power reactor program. In addition to the ELPHR, the AEC feels that the successful construction and operation of a practical demonstration reactor will encourage the process industry to construct many such reactors using their own resources. If these programs can be pursued as contemplated, it is anticipated that low temperature process steam produced from a nuclear reactor will be feasible within the next ten years and that persons contemplating the production of potable water from sea water will be able to buy nuclear heat sources as a standard item of equipment. As previously indicated, however, the economic production of low temperature steam is only one factor involved in the possible production of competitively priced potable water from brackish or ocean water."

Maritime Propulsion

The propulsion of merchant ships offers much promise as an application of nuclear power. There is no question of the technical feasibility of nuclear propulsion. This has been clearly demonstrated by the Nautilus and other nuclear powered submarines and by the Soviet icebreaker, the Lenin. The N. S. Savannah is expected to demonstrate the operation, maintenance and acceptability of nuclear merchant ships in domestic and foreign commerce.

Economic feasibility remains in some doubt but, as in the case of low temperature process heat, there are certain favorable indications. We note, for example, that estimates of nuclear fuel costs are now approaching, and if present trends continue, may become less than fossil fuel costs.

It is further apparent that nuclear operation would lend itself to a reduction in shipboard labor requirements through automation. This would reduce not only the direct costs for labor but also those for supporting requirements such as housing and food.

With both fuel and labor requiring less space in a nuclear than in a conventional ship, there would be a corresponding advantage in cargo carrying capacity. Further cargo increases may be accomplished through better techniques for handling cargo and other improved port procedures which are being developed primarily for nuclear ships.

Nuclear ships also have a weight advantage in that the weight of nuclear power plants plus fuel will be less than that of conventional plants plus fuel.

In addition, it is expected that use of nuclear ships will make practical the attainment of higher speeds, since incremental costs incurred to obtain increased power and speed will be less in a nuclear than in a conventional ship.

Economic studies indicate that nuclear propulsion is especially suitable for large tankers on long runs, and this may well be its first large scale marine use. Since such tankers customarily make their runs fully loaded, the weight reductions made possible by nuclear propulsion plants can be fully converted to cargo capacity. The long routes and short turn around time characteristic of tankers will result in a high load factor favorable to nuclear operation.

Following closely behind the tanker as candidates for economic use of nuclear propulsion are large ore carriers, general cargo carriers, icebreakers and passenger vessels. The high specific power offered by nuclear reactors may well find application in more advanced craft such as the hydro foil, submarine tanker or bulk carrier.

More economic transportation is but one of the benefits confidently expected from nuclear ships. Their ability to remain at sea for prolonged periods may also make possible for man a more thorough utilization of the resources of the ocean than has been possible heretofore.

Electric Power Reactors Other Than for Central Stations

Small power reactors are being developed in the military reactor program which will provide electricity other than on a central station basis to meet special requirements. One group of reactors is designed so that its parts are transportable by air. This is especially suitable for assembly and use in remote locations, as at a polar exploratory base.

While the power from these reactors would be costly compared with central station rates in the United States, their relative freedom from dependence on fuel supply might provide the only, or at least a superior, way of getting specific jobs done. It is estimated, for example, that a 20,000 ekw nuclear plant would each year render unnecessary fuel shipments requiring some 700 railroad coal cars or from 8 to 12 oil tankers.

Another type of reactor would be mobile and hence relocatable. This type could provide emergency power in disaster areas, and serve other demands of a transitory nature.

Most of the small power reactors being developed for use in remote areas or for providing emergency power supplies are also designed to provide modest amounts of space heat.

Industry studies have been under way for some time on the possibility of a nuclear powered locomotive. Formidable safety problems and limitations on the size of railroad equipment remain to be overcome, however, and this application seems remote at present.

A similar situation prevails with respect to use of reactors to propel vehicles used in highway transportation. Safety problems would be less worrisome in remote areas, however, and consideration has been given to a nuclear powered, off-road, overland cargo carrier for use in such locations.

Reactors as Sources of Process Radiation

Nuclear reactors offer great promise as sources of ionizing radiation. There are presently several products being manufactured in the United States which use electron beam or radioisotope radiation as an important step in the over-all process. For example, radiation is used to sterilize surgical dressings and sutures. In another case, radiation is used to cross-link

polyethylene tape, providing improved physical properties. A third example is the use of radiation-induced graft co-polymerization to modify plastic surfaces, for example, to produce Teflon that is both bondable and dyeable.

Despite these successes, we have barely tapped the potential promise of high-level radiation. Numerous research projects are attempting to extend the practical applications of this new processing agent. Efforts are being made, for example, to learn more about the effects of controllable parameters, such as temperature, pressure, and phase, on known radiation reactions. Among the specific relations being studied are the effect of phase on the radiation-induced nitration of cyclohexane, the variables affecting yields of nitrogen dioxide produced from oxygen and nitrogen, and the effects of trace impurities on yields of a number of simple radiation reactions.

Development of radiation processes for producing specialty chemicals having high market values is receiving a great deal of attention. Greatest economic promise attaches to those processes involving high yields per unit of radiation or producing high molecular weight materials. Typical of these are the processes encountered in polymerization and graft co-polymerization.

The use of radiation to improve the economics of existing conventional processes by supplementing other sources of energy also is being investigated. Presently, the petroleum industry is examining the use of radiation where an existing process may require rather high temperatures and pressures. The use of radiation should permit a decrease of the process temperature and pressure requirements. At the high production rates common to the petroleum industry, minor process improvements can mean great savings. Experimental studies of the effects of radiation upon catalysts and catalytic activity are also under way.

In general, it may be said that the uses sought for ionizing radiation are those in which it has a premium value over and above other forms of energy. This is because of the high cost of radiation. Nuclear reactors may contribute to practical large scale application by sharply reducing the cost of industrial radiation. Especially under study is the use of the kinetic energy available in reactor fission products for inducing chemical reactions. Fission fragments have ranges in the order of microns in solids, millimeters in liquid, and centimeters in gas. Therefore, solid fuels must have dimensions in the order of microns for the fission fragments to escape. Glass wool or dust particles containing U-235 are examples of fuels that might be used. Main interest in the use of fission fragment energy has centered on a process for the production of nitric acid from oxygen and nitrogen. Other potentially economic processes include the production of phenol, acetylene, and methane.

In considering the use of nuclear reactors as sources of radiation, we need not limit ourselves to the use of the fission fragments. While it is true that 85 per cent of energy released by fission does not appear as fission fragment kinetic energy, there are other sources of energy that merit attention.

One of the power reactors to be constructed in the United States utilizes liquid sodium as the reactor coolant. At relatively small cost, four megacuries of sodium-24 might be made continuously available from this reactor as a source of radiation power. The dose rate and specific activity of the liquid sodium are determined by reactor specifications. For a 250-megawatt reactor, one can obtain a dose rate of up to 200,000 rad per hour. Another reactor concept making use of about 7 or 8 per cent of fission energy as ionizing radiation is an organic moderated reactor. In this scheme an organic fluid which is the material to be processed is utilized as the primary reactor coolant and moderator. It is estimated that a 20-megawatt organic reactor can process more than a million megarad-pounds of fluidized material per hour. These other approaches have the advantage of low radioactivity contamination of the chemical formed.

We have thus begun to think in long-range terms of developing nuclear reactors as chemical factories. Reactors are capable of producing huge quantities of chemicals or modified materials at relatively low rate cost. Separation of the various products formed would probably be the most expensive step in their production. There is even promise for large-scale production of several chemicals concurrently.

STATUS OF MERCHANT SHIP NUCLEAR PROPULSION PROGRAMS IN VARIOUS COUNTRIES

Based upon information received from AEC and Maritime Administration Foreign Representatives, State Department foreign economic specialists and contacts with foreign industrial, governmental and maritime officials, it is apparent that considerable interest in nuclear propulsion is being shown in the following eight maritime nations:

Japan
Germany
United Kingdom
Norway
France
Italy
The Netherlands
Sweden

These countries are among the leading maritime nations of the world, and together with the United States own and build 70 per cent of the world's commercial shipping. Merchant shipping is a very important segment of their economy and contributes in a major way to their national incomes. They therefore have a definite incentive to develop nuclear merchant ships if an economic advantage is believed to result.

The nuclear activities of these countries reported to date have consisted of investigation of reactor and ship problems, preparation of feasibilities studies and engineering of specific reactor-ship applications. Nuclear ship construction has not yet been attempted.

The reactor systems which are being investigated are similar to those which the AEC believes have advantages for nuclear merchant ships, and include pressurized water, boiling water, organic moderated and gas cooled reactor types, with ratings ranging from 30 MW to 180 MW thermal. Ships under consideration include tankers, cargo-passenger, and special type vessels such as oceanographic survey and immigrant ships. All of these countries have sent at least three engineers to the United States to participate in the AEC's N. S. Savannah Training and Observation Programs. These include nuclear and marine engineers, and naval architects, some of whom have been engaged in nuclear marine propulsion activities in their own country for several years.

Russia was not listed with the above countries as there is little information available regarding their nuclear ship activities other than the limited information on the Lenin. During the October 1959 visit of Soviet Scientists, the statement was made that the USSR would not build

any additional nuclear merchant ships until the Lenin has been fully tested and her experience has been evaluated.

United States

The present U. S. program in the field of nuclear power for merchant ships is briefly as follows:

(a) In 1960 the N. S. Savannah will begin operation. During the first 2 to 3 years of operation, the ship will be utilized to test and demonstrate the operability of improved components and systems for future ships.

(b) Studies are in progress to determine the most suitable reactor system for early prototype application to a tanker. This work assumes sea going operation of the ship in 1964 and the submittal of a report to the JCAE by April 1, 1960.

(c) Work is in progress to develop a reactor plant which holds the highest potential of low cost propulsive power from a compact plant. The present program of research and development of the Maritime Gas Cooled Reactor closed cycle gas turbine system could permit the initiation of construction of a land-based prototype in FY 1962.

(d) A modest program of design feasibility studies of shielding, containment, ship structure, reactor and support equipment aimed at the economic applications of nuclear power to certain types of merchant ships is being pursued.

Russia and East Germany

Russia and her satellites have been excluded from the list of those most active only because we have little knowledge of their activity or interest other than that related to the Icebreaker Lenin. A recent article on the Lenin in a USSR magazine made no mention of other aspects of the Russian Nuclear Ship Program. Other reports, however, do indicate interest and activity in smaller river craft; a recent report also states that the "Warnow yard at Rostock, East Germany, is expected to complete the first East German nuclear powered ship by 1965."

Japan

No firm action has been taken by Japan toward the appropriation of funds or the choice of a ship. The 25-man mission which visited the U. S. in October and November of 1959 gave rather strong indications that Japan

would buy rather than build its first marine propulsion reactor. It is noted that Japan's shipbuilding industry has a substantial cost advantage over other major maritime nations for conventional ships and this will equally apply for nuclear applications; insofar as nuclear experience is concerned, a number of Japanese marine and nuclear designers, naval architects and engineers have been trained in recent years in the United States, English and German nuclear establishments. Hence the competitive potential is very high even though no "hardware" work has yet been initiated.

West Germany

In May 1959, the Federal Atomics Ministry granted approximately $4 million for the construction of an OMR prototype reactor. On November 25, 1959, the industry-government group announced that the reactor would be installed in a tanker, The Esso Bolivar, (15,256 DWT) in December 1960. The work to be undertaken at Hamburg was reported to cost $5 to $7 million. The owners of the Esso Bolivar have offered the ship gratis provided the construction project can be approved and the money appropriated by mid-1960. There has been no report made on actual start of construction.

United Kingdom

A joint nuclear-maritime group, similar to ours, has been engaged in feasibility studies, and has received proposals from nine prospective builders for the construction of their first nuclear ship. Of these, three proposed a gas cooled reactor, two a PWR, two a BWR, one an OMR and one a Heavy Water Moderated Reactor. These proposals were reviewed and evaluated by an industry-government committee (The Galbraith Committee) appointed by the Minister of Transport. Their report was made public December 18, 1959, along with a Ministry announcement that firm detailed engineering proposals on a BWR and OMR 65,000 ton, 20,000 shaft horsepower tanker were being solicited. It is anticipated that a decision will be reached in mid-1960, and that a program will be presented to Parliament for appropriation late in 1960.

Norway

Norwegian Shipbuilders and the Institute for Atomic Energy have been actively engaged in nuclear ship studies for several years and are concentrating on the BWR system. In September 1959, the combined group presented to the cabinet a proposal for the construction of a BWR prototype in a sphere to be placed in a fjord for experimental pitch and roll measurements during reactor operation. This project has the intriguing title of "Project Rock and Roll".

France

Four industry groups have worked with French nuclear and maritime Government organizations on two PWR, a BWR and a gas-cooled reactor propulsion system. It has been reported that the construction of a land-based prototype gas-cooled reactor is now under serious consideration by the Government.

Italy

A combination of the largest shipbuilder (Fiat) and the largest machinery manufacturer (Ansaldo) in Italy have prepared a detailed report on a proposed 74 MW pressurized water reactor. No immediate construction plans have been announced. The new Italian luxury liner Leonardo da Vinci has been designed so that, if future economics warrant it, nuclear power can be installed.

The Netherlands

A recently issued report described studies on two rather small PWR reactors in the 4500 and 7500 shaft horsepower range; the Netherlands has also explored the possibility of installation of a larger reactor system in an existing tanker. This is an industry-governmental cooperative effort being carried on with a relativelysmall budget. So far as is known, there are no immediate plans for requesting an appropriation for nuclear ship construction.

Sweden

Major shipbuilding firms in the Gothenburg area have financed studies of reactor systems for possible maritime application, but the work has been on a small scale and no immediate prototype or ship construction plans have been revealed.

Denmark

Danatom, a private association supported by industry was reported in September 1959 to be "working on plans for Denmark's first nuclear powered ship."

LETTER REQUEST TO ATOMIC ENERGY COMMISSION

* * * it would be very much appreciated if you would obtain for us a brief statement of the status and prospects for peaceful uses of atomic energy employed in the form of explosions under controlled or semi-controlled conditions. These are the applications which are encompassed under the name of PLOWSHARE.

* * * * * * *

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

* * * * * * *

In your letter * * * you requested a brief statement on the Status and Prospects for Peaceful Uses of Nuclear Explosives (Project Plowshare). I am happy to enclose a copy of the requested report * * *.

STATUS AND PROSPECTS FOR PEACEFUL USES OF NUCLEAR EXPLOSIVES (Project PLOWSHARE)

1. Preliminary studies concerning possible peaceful uses of nuclear explosives were initiated in 1957 at the Lawrence Radiation Laboratory, Livermore, California. Subsequently, in April 1958, the Commission approved a program, called "Plowshare," to be directed toward determining the feasibility of such potential peaceful applications of nuclear explosives.

2. Some of the possible peaceful uses of nuclear explosives are:

a. Civil Engineering.

Large volumes of earth and rock might be moved or broken for civil engineering projects with nuclear explosives at costs below those of conventional methods. Typical of such projects are excavation for harbors and canals, clearing of navigation obstructions, and creation of surface or underground water storage facilities.

b. Exploitation of Natural Resources.

Nuclear explosives might be used to fracture or to gain access to oil and other mineral deposits and thereby reduce the cost of recovery.

c. Power and Isotope Production.

The energy released and trapped by fully contained nuclear explosions offers a possibility for use in power and radioisotope production. The energy stored as heat might be released in a controlled manner by use of a transfer agent such as water, carbon dioxide or nitrogen, and used industrially or in the production of electric power. The neutrons released

by the nuclear explosion could bombard an appropriate substance and result in mass production of man made isotopes. It appears that power and isotopes might be produced in this manner less expensively than by other techniques.

d. Scientific Uses.

Valuable basic data in the fields of seismology, geology and special chemical reactions unattainable with conventional laboratory techniques might be obtained from contained nuclear explosions. In addition, information on the diffusion of heat and on the fracture spectrum in rocks of varying characteristics also could be obtained and could be immediately applied to the determination of the feasibility of several of the other possible peaceful applications. The RAINIER underground shot in September 1957 provided some information on the effects of nuclear explosives in tuff and was supplemented by the underground shots of October 1958. This most recent information is being collected and reports are being prepared.

3. Numerous theoretical studies have been initiated under the Plowshare program. Reports of those studies which have been completed and published, together with other relevant literature are listed in the attachment. In addition to theoretical studies, the Commission has under consideration several possible experiments which would assist in the evaluation of the feasibility of certain peaceful applications of nuclear explosions. These possible experiments are:

a. Project Chariot.

To obtain engineering and scientific information applicable to the use of nuclear explosives for purposes such as harbor

or channel excavation the AEC is making studies to determine the feasibility of conducting a proposed experiment near Cape Thompson, Alaska. Field work on this project has included studies on environmental problems including botanical, mammalian, marine and human ecology. In addition geological, hydrological, and meteorological studies are being made. The purpose of these studies is to gather the information needed by the Commission to assure itself on the public health and safety aspects on this proposed experiment as well as to provide information needed in designing the experiment. The Commission has not as yet authorized the conduct of the experiment and will not do so if these studies show that there is a possibility of danger to the public health or of serious ecological disturbances.

b. Natural Resources.

The AEC is examining the applicability of using nuclear explosives as an aid in recovering oil from oil shales. A nuclear explosion might be used to fracture the relatively impermeable oil shale; the induced permeability might then be used for a controlled in situ retorting of the kerogen (the source hydrocarbon). The experiment would determine if oil shales can be broken in sufficient quantities and to proper size to permit oil recovery. Variants of this approach might be used to exploit other mineral deposits. In addition to the above, an oil company has proposed to the Canadian Government and to the Commission and offered to finance an

experiment to determine the feasibility of using nuclear explosives to aid in the recovery of oil from Athabaska tar sands in Alberta, Canada. This proposed experiment is now being studied by the Canadian Government.

c. Project Gnome.

The AEC has designed an experiment to provide information on the possibilities of a contained nuclear explosion generating useful power, and producing and recovering isotopes. Massive salt deposits are dry and have proper solubility and suitable strength for such an experiment; hence, after a review of salt deposits in this country, a site in the Salado salt formation in New Mexico was selected for detailed investigation. Surveys and studies have been underway since August 1958 to determine the feasibility and safety of conducting the experiment in this location. Early in 1959 the AEC conducted a series of high explosive tests at this site to obtain certain seismic data and record the magnitude and characteristics of shock produced.

These studies have been evaluated by a panel of consultants, nominated by the National Academy of Science and appointed by the Atomic Energy Commission, who are recognized experts in the fields of Seismology and Geophysics. This panel concluded that the experiment can be conducted safely with respect to seismic effects. Other studies indicate that the experiment can be conducted safely with respect to radiological effects.

As in the case of Project Chariot, the Commission has not as yet authorized the conduct of the experiment.

4. From the above it can be seen that the Plowshare program is still in an early study stage. It is estimated that a period of several years will be required before the feasibility of the use of detonations for any such peaceful uses can be established.

Attachment:
Bibliography: Peaceful Uses of Nuclear Explosions

January 19, 1960

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LETTER REQUEST TO ATOMIC ENERGY COMMISSION

This will confirm our discussion * * * concerning the preparation by the Commission of a background paper on the isotope, radiation, and research programs of the United States. This background paper is requested in connection with the "Review of International Atomic Policies and Programs" of the United States being conducted by Mr. Robert McKinney for the Joint Committee.

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It is our hope that this paper can be in the nature of a monograph dealing with the record to date. As you know, there are other papers being prepared dealing with the institutions through which these programs are being forwarded, as well as on other assistance programs going forward in parallel.

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COMMUNICATION FROM THE ATOMIC ENERGY COMMISSION

The purpose of this communication is to inform you that while our Division of Biology and Medicine is drafting * * * reports on the status of the technology of atomic energy applications in agriculture and medicine and public health, you should also request the Department of Health, Education, and Welfare—U.S. Public Health Service and the Department of Agriculture * * * to submit information * * * on atomic energy applications in medicine and public health, and agriculture respectively.

TRANSMITTAL LETTER FROM THE ATOMIC ENERGY COMMISSION

I am happy to enclose three papers prepared by the Commission's Division of Biology and Medicine. These reports * * * are as follows:

Impact of Radioisotopes on Medical Diagnosis and Therapy
Use of Radioisotopes and Radiation in Agriculture and Plant Studies
Impact of Radioisotopes on the Life Sciences

The foregoing papers summarize in part the information set forth in the recently released report "Radioisotopes in Science and Industry."

THE USE OF RADIOISOTOPES AND RADIATION IN AGRICULTURAL AND PLANT STUDIES

Plant Studies.
- Radiation Genetics of Plants.
- Photosynthesis.
- Plant Metabolism.
- Translocation of Materials.
- Soil as a Source of Nutrient.
- Uptake of Nutrients.
- Foliar Absorption of Nutrients.
- Soil Density and Water Content.
- Plant Growth Substances.
- Plant Growth Regulators and Herbicides.
- Plant Diseases and Fungicides.

Insect Studies.
- Biological Studies of Insects.
- Insect Destruction.
- Insect Sterilization.
- Insecticides.

Biosynthesis of Drugs and Other Compounds.

Farm Animal Studies.
- Nutrition of Farm Animals.
- Biochemistry of Body Processes in Farm Animals.

Use of Radioisotopes and Radiation in Agricultural and Plant Studies [1]

Radioisotope techniques are applied to a wide range of problems in agricultural research, ranging from applied studies of immediate practical importance to abstruse basic investigations. Isotope techniques permit the solution of problems that cannot be approached in any other way; they often permit the solution of more routine problems faster and more cheaply than do conventional approaches. Isotopes have been of particular value in understanding the very complex biological-chemical-physical processes of living creatures and plants which provide the basis of agriculture production.

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[1] Reference: "Radioisotopes at Work for Agriculture," SRIA–9, A. Gerloff Homan and Richard R. Tarrice (Stanford Research Institute, Menlo Park, California), October 1959. 200 pages. Available from Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C., price $3.50.

PLANT STUDIES

The Commission supports basic studies on plant physiology and biochemistry, plant genetics and plant pathology. Generally speaking, this research aims at eventual agricultural benefits, but does not cover practical farming practice. Many thousands of studies in plant science have been published; this report describes only major areas of research.

Radiation Genetics of Plants

The production of improved agricultural and ornamental plant varieties requires many years of deliberate breeding and selection to obtain desired characteristics. The breeder needs a large pool of genetically variable source material for selective combination into a new variety. Ionizing radiation helps to provide this pool, since it produces rapidly a great variety of genetic changes in plant stocks.

Using radiation-altered stocks, abrupt improvements in resistance to disease have been produced. Small improvements in yield or in maturation time of crops have been achieved. The synthesis of small, independent, but scattered changes into one new variety can give surprisingly good results. Favorable genetic changes make up, of course, only a tiny fraction of all the changes produced by radiation and the plant breeder still must accomplish patient and careful elimination and selection.

Irradiation of seeds used extensively in the United States has produced a number of promising mutations. Two new plant varieties obtained in this way have been formally released to plant breeders for practical agricultural use. One, the "Sanilac" bush navy bean, in several years of testing, outproduced the parent variety by approximately 30 percent per acre, and, in addition, required fewer days from planting to harvesting. The other is an improved variety of peanut with higher yield and greater disease resistance which was released last year.

Ionizing radiation also is used to produce somatic mutations in plants which can be propagated with cuttings or grafts. Desirable color changes in experiments with apples and improved peach varieties have been obtained in this way. Another technique involves using radiation to fragment chromosomes—genetic materials in reproductive cells—to permit recombining genes or sections of chromosomes in

desired crosses. This technique has been successfully used in introducing genes for leaf rust resistance into wheat.

Disease-resistant strains have been reported in experiments with wheat, oats, and flax. High-yield dwarf forms of cereal grasses have been observed which suffer less wind damage than do customary strains. Encouraging results are reported on attempts to use mutation to eliminate a factor toxic to livestock from certain otherwise useful forage plants. Fruit trees grown in low levels of gamma radiation for several years and permitted to return to normal growth, are being analyzed for possible useful mutations.

Two beneficial mutations have been reported in such experiments on peach trees. One branch of a Fairhaven peach tree bears fruit which ripens approximately 10 days earlier than normal. A branch on a different tree ripens its fruit some 3 weeks later than normal. These two radiation-induced mutations may lead to increasing by more than a month the season over which the fresh fruit can be available. Buds from these mutations now will be grafted on other trees, in an attempt to propagate the ripening qualities. When a large enough population of the new types can be established they will be critically tested to see if they are of good quality for future commercial use.

Photosynthesis

One of the best known applications of radioactive tracers to biological problems has been to the study of photosynthesis. In some respects photosynthesis may be regarded as the single most important chemical reaction in the world since it is the life process of plants that ultimately provides the energy for almost every type of living organism. In the photosynthetic process plants absorb electromagnetic (light) energy using the green pigment (chlorophyll) in the leaves. This energy is used for converting inorganic carbon dioxide and water into energy-containing food substances such as sugars and starch. All food consumed by humans initially comes from the photosynthetic reaction in green plants.

Photosynthesis has been studied for almost 200 years. Until 1954, however, about all that was known was that light energy absorbed by the chlorophyll was used to split water with the production of a reducing agent and an oxidizing agent, the latter finally producing the oxygen gas evolved in photosynthesis. The reducing power in

some way was used to convert the inorganic carbon of carbon dioxide into organic materials, a process termed carbon dioxide fixation.

In 1954 reactor-produced radioactive carbon 14 became available as a tool for photosynthesis research. In the succeeding years, it permitted a major breakthrough in the study of carbon dioxide fixation. The general experimental approach is to give a photosynthesizing plant carbon dioxide in which part of the carbon is carbon 14. Samples of the plant are killed after various periods of time, an extract prepared, and the various chemical compounds in the extract separated by a process called paper chromatography. Any compound containing carbon 14 must have been derived from the carbon dioxide taken in by photosynthesis. In this way it has been possible to identify ultimately each of the steps involved in the fantastically complicated process by which carbon dioxide from the air is converted into the organic compounds of the plant.

The process by which water molecules are split up in photosynthesis is very poorly understood. Unlike carbon, there is no useful radioactive isotope of oxygen available to help trace the reactions involved. However, scientists at the University of California, Berkeley, have recently developed a very ingenious technique for studying the water-splitting reaction. Photosynthesis experiments are carried out using water containing heavy oxygen, oxygen 18, instead of ordinary oxygen 16. The compounds produced are separated by paper chromatography as in the carbon dioxide fixation studies and are then irradiated in a proton beam from a cyclotron. This converts the stable oxygen 18 into radioactive fluorine 18. Any radioactive compounds which appear must contain oxygen produced from the photosynthetic splitting of water. This new technique involving atomic energy offers an excellent chance of completing the story of photosynthesis.

The studies of photosynthesis described were carried out with intact, living cells of plants. In recent years, much work has been done with isolated parts of cells to find out just what structures within the cell carry out certain metabolic processes.

In this approach, plant cells are ground up and green chloroplasts, the microscopic structures of the plant cell which contain all the chlor-

ophyll, are separated from other cellular components. This permits studying the process carried out by the chloroplasts in a simpler system free from the thousands of other chemical reactions which go on in living cells.

The isolated chloroplasts have been found capable of carrying out the overall photosynthetic reaction; even more important, they permit studying some partial reactions. For example, most chloroplasts, when illuminated, will carry out a reaction in which water is split. Properly prepared choloroplasts also will carry out a previously unknown process called photosynthetic phosphorylation which is measured using radioactive phosphorus. In this process, light energy is used for the synthesis of high energy phosphate compounds, which are in turn used to drive other reactions in cells.

Plant Metabolism

Metabolism is generally defined as the sum total of all the chemical reactions occurring in an organism. Photosynthesis is a typical example of an over-all plant metabolic process, and perhaps the best studied of all plant metabolic reactions. There are many tens of thousands of different chemical reactions going on in plant tissues, a degree of complexity which makes very difficult the study of a particular reaction. Thousands of scientific papers have been published in recent years describing research where radioactive tracers have been used in the study of specific plant metabolic processes. A few examples are described here.

A great deal of work has been done on the detailed mechanisms by which *carbohydrates* are broken down in plants. In animal tissues, glucose is oxidized through a complicated series of reactions in which the 6-carbon glucose molecule is first split into two 3-carbon molecules. Earlier work indicated this was the principal path of carbohydrate catabolism in plants also. Recent work using carbon 14 as a tracer has shown, however, that there are two additional pathways of glucose breakdown in plants which, in some cases at least, are quantitatively more important than the classical pattern. Both these pathways (the pentose-phosphate pathway and the glucuronate-decarboxylation pathway) involve a splitting of the 6-carbon molecule into a 1-carbon and a 5-carbon molecule. These processes are involved in plant respiration, and especially in the synthesis of the plant cell wall. Studies such as these were possible only through the availability of glucose in which different carbon atoms were individually labeled.

Recent studies indicate that the mechanisms involved in plant synthesis of certain *fatty acids* is considerably more complicated than previously thought. Most plants synthesize such fatty acids as oleic and linoleic from acetate. Very recently it has been found that light together with the vitamin biotin are involved in these processes, at least in some plants. The actual mechanisms are still unknown, but tracer techniques should help elucidate these details.

The presence of high concentrations of a sulfolipid was recently demonstrated in plants. The only other compound of this type known is a cerebroside sulfate found in nerve tissue. The structure of the new compound was determined using plants labeled with sulfur 35, phosphorus 32 and carbon 14. So far this compound has been found only in green plants and is not present in animals or in non-photosynthetic

plant tissues. As yet nothing is known of the function of this sulfolipid in plant cells. Several other unusual types of fatty materials have been shown to be involved in plant metabolism, including a group of galactosyl glycerides.

The finding of diglycerophosphate and its acylated derivative phosphatidyl glycerol in algae led to a recognition of these compounds in all additional plant and animal tissues studied. An interesting neutron activation technique termed "activation chromatographic analysis" has been recently developed for analyses of compounds of this type on paper chromatographs similar to that described in water-splitting studies. Quantitative analyses of the compounds was possible by comparing their induced radioactivity with that induced in one microgram reference samples of phosphorus placed at the edges of the chromatogram.

Translocation of materials

In plants, the transport of dissolved materials from one region of the organism to another is termed translocation—corresponding to circulation in animals. Water and minerals taken up by the roots are transported to stem and leaves; sugar and other organic compounds synthesized in the leaves are carried to all other parts of the plant. Knowledge of the translocation processes, especially at the cellular level, is far from complete. From the agricultural point of view, studies of translocation are important because it is involved in such processes as the transport of weedkillers, the movement of disease-producing viruses in plants, the movement of nutrients applied to the leaves, and the water economy of the plant.

Older studies have given a gross picture of translocation—that water and minerals move primarily through the woody parts of the plant while organic materials such as sugar are translocated through the bark. The advent of isotopic techniques permitted a really sustained and comprehensive program of investigation. A number of studies indicate that, in many plants, carbohydrates are translocated only in the form of the sugar sucrose. For example, in a study in which a single leaf on a grapevine was fed carbon 14, sections of the stem later showed that only sucrose was translocated from the leaf along the stem.

The upward flow of water and mineral salts in the vine has not been explained in detail, and there still are at least four major theories which attempt to account for the movement of organic materials in the bark.

Soil as a source of nutrient

Early soil fertility research used cyclotron produced radioisotopes. When larger quantities of reactor-produced radioisotopes were made available by the Commission, a central facility was set up at the Plant Industry Station of the Department of Agriculture in Beltsville, Md., to prepare various types of tagged fertilizer which then were made available to experimenters all over the country. A tremendous literature on the results was produced. A few typical studies are reported in this section.

Radioactive phosphorus has been used more extensively than any other element in soil studies. Large numbers of experiments have been carried out to determine the best chemical form of phosphorus

for a given soil and crop, the mobility of phosphate in a given soil, the relative degree of utilization as between applied phosphate and phosphate occurring naturally in a soil, and chemical interaction of applied phosphate with insoluble phosphorus compounds in the soil.

Commercial phosphate fertilizers include superphosphate, calcium metaphosphate, dicalcium phosphate and liquid phospheric acid. Tests using these fertilizers tagged with radiophosphorus showed for example that dicalcium phosphate was an effective fertilizer in acid soils, but was rather inefficient as compared to super phosphate in alkaline soils. Studies of this type led to a new technique of fertilizing—by adding liquid phosphoric acid to irrigation water. The availability of phosphorus from different organic sources such as plant remains and manures also has been studied by tagging these materials.

Knowledge of movement in the soil of phosphorus from a particular fertilizer is of importance in determining the best way to apply that fertilizer. Generally speaking, it has been found that phosphorus moves so slowly in soils that, for many crops, this fertilizer applied to the surface does not become available during the first year. Corn, for example, uses some recently applied phosphorus when the plants are young and the roots are near the surface. As the plants get older, the roots penetrate more deeply and the plants then must depend on phosphorus already present in the soil. Studies of this type save large amounts of money for farmers every year since they permit more efficient fertilizer practices.

Calcium has been similarly shown in isotope studies to move very slowly through soils, and many highly calcareous soils yield very little calcium for plant growth because calcium carbonate does not appear to give up appreciable quantities of its calcium.

Plants growing in many calcareous soils are chlorotic or pale green instead of the normal dark green, often because of a lack of *iron* in the plant. The cause of reduced iron availability in these soils still is not entirely clear. Addition of certain other minerals including phosphate and bicarbonate often improve the availability of iron, or iron may be added in a chemical form that is not bound as strongly in the soil. Studies have developed so-called iron chelates, which are compounds of iron with certain organic molecules and these complex forms permit normal iron nutrition of plants in soil which could not otherwise be used for crops. By using radioiron 55 or 59 to tag the iron, and by radiocarbon 14 to tag the organic part of the chelate, the stability and methods of breakdown of the chelates in soil are being studied in detail.

Similarly the movement and uptake of *zinc* has been studied using radioactive zinc 65 in various chemical forms. Zinc in inorganic form moves through many soils very slowly, but zinc chelates move rapidly and are readily available in plants.

Uptake of Nutrients

Materials essential for plan growth include: carbon dioxide usually obtained from the air; water usually obtained from the soil; and a variety of such elements as phosphorus, nitrogent, sulfur, potassium, calcium, iron, and magnesium usually obtained as ions from the soil. The ability of the plant to take up the ions, as contrasted with their

availability in the soil, also has been studied with radioactive tracer techniques.

Availability of radioactive forms of the minerals permitted carrying out experiments under natural conditions with very low concentrations of minerals, whereas earlier use of stable isotopes, necessitating less sensitive analytical techniques, made it necessary to use abnormal concentrations. The great sensitivity of raido-traced techniques also permitted making uptake measurements in minutes and hours, whereas older techniques required weeks. The shorter times also permitted differentiation of the uptake process from translocation processes.

The uptake of minerals by roots is an extremely complicated process, involving at least two major mechanisms.

First, some ions move more or less freely (passive transport) into the plant root by diffusion. These ions then move to the central region of the root by diffusion, perhaps aided by photoplasmic streaming. Finally the ions are moved upwards in the plant with the flow of water from the roots. Passive transport apparently plays a more important role in mineral uptake when plants are losing water rapidly by evaporation from the leaves. This mechanism may represent the principal way by which minerals reach the stems and leaves of plants.

The other mechanism of mineral uptake (active transport) is more selective and requires expenditures of energy by the plants. It appears to be the principal method by which young roots pick up and concentrate minerals. The so-called "carrier" hypothesis has been developed in an attempt to explain active transport. According to this theory, the ions combine with carriers at the outer surfaces of root cells (membranes), the ion-carrier complex passes through the membrane, and the ion is released on the inside of the membrane. This transport occurs only in one direction. The carriers are highly specific with respect to the ions with which they combine. Tracer experiments involving mixtures of different ions indicate, for example that rubidium, potassium and cessium compete with one another for transport and therefore presumably all are transported by the same carrier. Sodium and lithium do not interfere with the transport of the other three ions, and therefore are regarded as being transported by other carriers. Calcium and barium compete with strontium; magnesium does not. Selonite competes with sulfate; phosphate and nitrate presumably are transported by other carriers. Such studies, little by little, are beginning to give a picture of how materials are taken up by roots.

Tracer experiments also have revealed that different regions of the roots behave differently with respect to uptake and movement of minerals. By applying isotopes to different, very restricted, regions of roots it has been found that materials taken up by the tips of roots are largely localized there. Materials applied further away from the tip (in the "root hair" zone) are moved into the center of the root and then up through the rest of the plant. Most of the water taken in by the plant enters through this latter region.

Foliar Absorption of Nutrients

Radioistopes made possible a simple distinction between foliar and root uptake of nutrients by plants and studies using this technique showed how general foliar uptake is. It is now known that a wide

variety of inorganic and organic nutrients can be efficiently taken up from sprays and used by the plant for growth. In future agricultural practice applying some nutrients by spray to the foliage may prove far more efficient than adding them to the soil with certain crops in certain soils.

Inorganic salts including phosphorus, sulfur, potassium, sodium, manganese, zinc, copper, chlorine and rubidium are taken up by leaves rapidly and moved throughout the body of the plant. Calcium, strontium, barium, cesium, iron, molybdenum, and ruthenium also are rapidly taken up by leaves but remain bound in some fashion at the site of entry. Many organic compounds also are rapidly taken up by leaves.

Although most of the nutrients studied were taken up rapidly by leaves, a number of variables were found to influence the rate of uptake. Some of these, such as the thickness of the cuticle on the leaf surface, or the amount of "fuzz" on the leaf surface, are related to the particular plant species involved. Alkaline solutions were absorbed more poorly than slightly acid solutions. Daylight favored absorption as did intermediate temperatures from 60 to 85 fahrenheit. Plants with a good nutritional status took up nutrients more slowly than those which were "starved".

Materials also will be lost by the leaves under certain conditions. For example, some nutrients picked up from the soil and moved up to the leaves will be leached out during a heavy rain. Even such organic materials as sugars produced by photosynthesis can be lost in this way.

It is probably too early to assess the future importance of foliar nutrition in agricultural practice, but the availability of radioactive isotopes opened up the field for study far sooner than otherwise would have been possible.

Soil Density and Water Content

The suitability of a soil for agricultural use is determined not only by its mineral composition, but by its physical properties as well. The major physical properties of soil concerned with plant growth are such mechanical characteristics as the ease with which growing roots and shoots can penetrate it, its water holding capacity and water content, and its permeability to oxygen and carbon dioxide.

Field measurements in soil physics are difficult since it is desirable that soils be studied in an undisturbed state, and radiation has been used successfully for two types of soil measurements which were difficult if not impossible in the past.

Measurements of soil density *in situ* provide valuable information to the soil scientist. These measurements now can be made by observing the absorption of scattering or gamma radiation in the soil under consideration. To apply this technique, two holes are drilled into the soil a few feet apart. A gamma source, such as cesium 137, is lowered to various depths in one hole and a sensitive gamma scintillation detector is lowered in the same fashion in the other hole. The amount of radiation absorbed at any given position is a measure of the soil density at that depth. Another less precise technique is to lower a backscattering gage—a combined gamma source and detector—into a single hole.

Both techniques measure total density of the soil—the combined density of soil plus water. Dry density of the soil can be calculated when the water content has been determined by another radiation technique.

Since water is a good moderator of fast neutrons, and soil a very poor moderator, a technique was evolved using a fast neutron source to measure water content of undisturbed soil. By determining the density of moderated, or slow, neutrons resulting when a fast neutron source is lowered into a hole drilled in the soil, soil moisture can be estimated to within one-half of one percent, and the measurements will be essentially independent of the nature and density of the soil. Modern equipment for such measurements is portable and reliable. A typical instrument consists of a scaler plus a small radium-beryllium fast neutron source, combined with a slow neutron detector in the form of a probe which can be inserted into the soil.

Another physical property of soil of interest is the rate at which gases will diffuse through its structure. The roots of plants consume oxygen and produce carbon dioxide. Thus, the rates at which these gases move through the soil are of prime importance in plant growth. It now is possible to measure accurately the rate of movement of carbon dioxide through soil by allowing carbon dioxide tagged with radioactive carbon 14 to diffuse through soil saturated with ordinary carbon dioxide.

Plant Growth Substances

Plant growth is regulated by the nutritional status of the plant and availability of organic materials produced in photosynthesis, but also by specific organic compounds produced in certain parts of plants and transported to other parts where they exert their effects even at extremely low concentrations. These compounds are termed plant growth hormones.

One group of plant hormones, the auxins, is involved in stem and root elongation, fruit growth, and bud growth. Many modern agricultural applications of the auxins have been developed including their use in selective weed control, control of fruit setting, control of preharvest fruit drop, rooting of plant cuttings, and production of seedless fruits.

Although a number of different compounds show biological activity, it appears that indoleacetic acid (IAA) may be the auxin most commonly involved. Thus the pathways by which this compound is synthesized and degraded in the plant, and the mechanisms by which it controls plant growth are of extreme interest to plant scientists.

It was suggested quite early in the studies of auxins that IAA was synthesized from the amino acid tryptophan, although it was not possible to show this experimentally with methods then available. In recent years, radioactive tracer studies have shown that not only IAA, but other hormone compounds as well, arise from tryptophan via indoleacetaldehyde. Among those are 5-hydroxytryptophan (which is converted to serotonin in the animal body) and indoleacetonitrile, which occurs in high concentration in certain plant groups. A kinetic study of auxin turnover found that in tissues of young grass plants 50 percent of the auxin molecules were replaced each hour.

The study of the mechanisms by which plant growth substances such as auxins control various aspects of growth has been difficult. Approaches involving radioactive tracers and radiation have been very useful. For example, the working hypothesis "no growth without auxin" is generally used. However, original attempts to demonstrate that auxin was required for the expansion of leaves failed—apparently because of the large amount of auxin manufactured in a young leaf. This was overcome by exposing the young leaves to X-ray some 60 hours prior to growth experiments to inactivate the enzyme system responsible for converting indoleacetaldehyde into IAA. By treating the leaves with auxin after irradiation it was possible to demonstrate a definite need for this substance. These results appeared to show that the "no auxin-no growth" hypothesis extended even further than previously suspected.

This new approach to studying the auxin metabolism of leaves has been made possible only by basic studies on the mechanism of radiation effects produced by ionizing radiations.

A primary problem to be resolved in learning about radiation effects is to understand the efficiency of the effect; i.e., the amount of damage from a given quantity of radiation. In the absolute sense, relatively little energy is absorbed by the organism that receives small radiation doses. Yet these doses result in profound physiological and morphological disturbances, even though the ionizations initially produced are 1 million to 10 million fewer in number than the molecules in any given tissue. The simplest interpretation of this phenomenon was that agents in the plant responsible for the turnover of many molecules were affected by radiation; i.e., that regulatory mechanisms of the cell were primary loci of radiation damage.

Work has shown that the auxin molecule in the plant is not itself sensitive to radiation damage. Yet the concentration of auxin in the plant drops sharply immediately after irradiation. The biochemical locus of radiation damage was shown to be a specific enzymatic reaction involved in auxin formation. Both in sensitivity, and in pattern of inhibition and recovery, the enzyme inhibition could be experimentally integrated with phenomena in the plant. Most enzymes in living systems resist immediate damage by ionizing radiation unless the radiation doses are very high. The process of auxin formation is unusually radiosensitive. It appears that the radiosensitive step involves an enzyme at a terminal stage in the process.

Plant growth regulators and herbicides

The plant growth hormones described previously exert their effects at very low concentrations. For example, indoleacetic acid at a concentration of 1 part in 100 million will produce measurable growth in certain plant tissues. As the concentration of plant growth hormones is raised they become very toxic to certain types of plants. This is especially true in the case of certain synthetic compounds such as 2,4 dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) which can be used to kill plants. The 2,4-D and 2,4,5-T are much more toxic to broad-leaved plants than to narrow-leaved plants such as grasses and grains, and usually are referred to as weed-killers or as selective herbicides. The 2,4-D, for example, can be used to kill dandelions selectively without harming the grass of a lawn.

Millions of dollars are saved annually in agriculture by use of selective herbicides, and many different types have been developed. For these compounds to act, they first must be absorbed into the plant, then translocated to the site of action in the plant body. The basic nature of those processes must be understood before weed killers can be used successfully, or improved ones developed. Since weed killers are effective at very low concentrations, use of radioisotopes has been absolutely essential to these studies.

Early work provided convincing evidence that labeled 2,4-D was readily absorbed through the plant leaf and carried to remote parts of the plant along with food materials. Knowledge of plant physiology permitted a prediction of the ultimate location of the 2,4-D molecules, testing proved the prediction accurate, and permitted interpretation of a large mass of field data on the use of 2,4-D. Other tests may have helped to explain partly why high rates of application of herbicides sometimes result in less efficient weed control than do moderate rates of application, and showed also that absorption of herbicides by leaves was somewhat less as the plant grew older and the leaves matured. This may explain why older plants may be more tolerant to herbicides than younger plants.

Field studies of other growth-regulating compounds, both labeled and unlabeled, have permitted many valuable interpretations concerning the function of herbicides. At present, results of such studies cannot be interpreted fully, and further work is being carried on.

Plant Diseases and Fungicides

Plants are subject to diseases to about the same extent as are animals, including man. Plant diseases, including those caused by viruses, bacteria, and fungi, yearly destroy an estimated $3 billion worth of useful plants in the United States alone. More than 50 fungus diseases attack sweet potatoes, and an estimated 20 to 40 percent of the crop is lost in the field, in storage, and in transit to market. This loss alone is estimated from $24 to $48 million per year.

Millions are expended on fungicides. For example, a disease known as Sigatoka attacks bananas in tropical America. Approximately 45 million pounds of copper sulfate are required each year to protect some 130,000 acres of bananas, and costs about $5 million a year.

Radioactive isotopes have been extremely useful in helping understand the mode of transmission of certain plant diseases, and the mechanism of agents which inhibit or kill disease organisms.

Since fungus diseases cause more damage to plants than those produced by viruses and bacteria, considerable work has been done on the transmission of fungus infections, and on fungicides, or chemicals to kill the infection.

The successful fungicide not only must control the disease, but it also must be compatible with fertilizer constituents and must not, either alone or in combination, injure the plants. Moreover, the compound must not be so toxic that its widespread use would present a hazard to human or animal populations. The cost of developing a new fungicide may require an investment of between $250,000 and $1 million. It is estimated that 999 out of every 1,000 compounds tested as fungicides or insecticides do not result in a satisfactory agent.

Radioisotopes can accelerate development of new agents by assisting in elucidating the metabolism of the fungus, and thus providing

greater precision in deciding the point of attack in the fungus cycle most suitable for control of the plant disease. Radioisotopes help also in investigating organic compounds used as agents. In many cases, only a portion of the molecule blocks the life cycle, whereas the remainder of the molecule is necessary to permit entry into the circulatory or metabolic system of the fungus.

The use of radioactive isotopes has made possible many types of investigations on fungicides which would be difficult or impossible by standard chemical methodology. For example, with small organisms such as fungus spores, it is difficult to determine the actual amount of chemical required for a lethal dose. The sensitivity of tracer techniques permits this as a routine measurement, even though the most useful fungicides are effective in extremely small doses. Another area of work is concerned with the metabolism of toxic materials by fungi in order to determine whether the material acts directly, or whether it is first altered chemically before acting as a fungicide. It has been established that some fungicides are partially metabolized with the production of carbon dioxide.

INSECT STUDIES

Radioisotopes have found an important place in studies of insects and other pests in efforts to control their spread and infestation of crops and animals. It has been estimated that destructive pests cause $3 billion of damage annually. They may destroy sizable proportions of growing food crops. Quality and yield may be reduced by infestations. Livestock tormented by them fail to gain weight and give less milk. In the home, they attack stored food, clothing, household furnishings, and buildings. They transmit many diseases of animals and man.

Insecticides are the most widely applied method of combating insects. Other common control methods are biological control, cultural practices, mechanical devices, and drainage and filling. In recent years, insect resistance to insecticides has created a problem. Radioisotopes have found applications in many studies in all these areas.

Other studies in which radioisotopes were used to tag insects have determined insect movement in a field, distance of range, migration, feeding habits and metabolism, and genetic changes.

Biological Studies of Insects

In biological studies to determine dispersal of insects and their flight range, various radioisotopes have been used as a tag either by applying it directly to the insect or by introducing it into the food. When insects later are recaptured, their range and the effectiveness of control procedures can be calculated. Mosquitoes, house flies, blow flies, and other agricultural and forest insects all have been studied by these methods.

Insect Destruction

Ionizing radiation in sufficient quantities can kill insects. The amounts of radiation required are many times greater than the levels required to kill animal species; on the order of 100 times the amount required to produce lethal effects in man. Studies now underway seek methods of applying these enormous amounts of radiation to

the problem of killing insects. One proposal has been to use irradiation from fission products to destroy insects in stored grains, processed and packaged foods, clothing, and wood products. Carpet beetles, cigarette beetles, and rice weevils can be killed by radiation doses of 65,000 roentgens. Other insects might require higher or lower doses. Among problems that would have to be solved before practical uses could be worked out are removal of dead insects from food processed this way, and the high cost of irradiating large volumes of commodities.

The Fission Products Laboratory of the University of Michigan has planned an irradiation unit for installation in a railroad boxcar. The unit will be capable of processing 6,500 bushels of material a day at an estimated cost of 6 to 8 cents a bushel.

Insect Sterilization

Levels of radiation sufficient to cause sterility in male insects has permitted the virtual eradication of the screw worm fly in many parts of the Southeastern United States. Studies conducted by the Department of Agriculture for several years indicated a method, and one season's experimentation on the island of Curacao, Netherland West Indies, proved an isolated insect population could be wiped out.

The method involves the release of sexually sterile male flies which, mating with normal females, produce no offspring.

After the initial success in Curacao in 1955, the State of Florida, together with four other southeastern States, joined the Department of Agriculture in 1957 in a cooperative program aimed at the elimination of the pest from the Southeast. Complete success already is in sight.

Success with the screw worm fly has stimulated similar studies to determine the effectiveness of this method for controlling or eradicating the Mediterranean fruit fly, the oriental fruit fly, the melon fly, and the tsetse fly.

Insecticides

Radioisotopes introduced into insecticides have provided means for studying their mode of action. Studies have been made of the residue of insecticides in food or agricultural commodities, and mechanisms by which organophosphates poison insects. Tracers also provide understanding of the nature of the toxic action in animals and plants. Dozens of materials have been labeled, including the chlorinated hydrocarbons, organophosphorus compounds, plant-derived and inorganic insecticides and fumigants.

DDT labeled with carbon 14 has been studied by a number of workers. Phosphorus 32 has been used to label and study the metabolic pathway of such organophosphorus insecticides as Parathion, Schradan, Dimefox, Thimet, Phosdrin, Delnav, DDVP, Dipterex, Viozene, Malathion, and many others.

BIOSYNTHESIS OF DRUGS AND OTHER COMPOUNDS

Many plants produce nitrogen-containing compounds known as alkaloids. Generally, the alkaloids have no known function in plants, but a number of them are physiologically active and useful as sedatives or tranquilizers, and in various other forms, for treatment of hu-

man and animal diseases. Drugs range from mild stimulants, such as caffeine, through more complex ones, such as quinine, morphine, and rauwolfia.

Considerable work has been done using radioactive tracers to study mechanisms of biosynthesis by which plants manufacture alkaloids. One of the simplest alkaloids is nicotine. Nicotine is synthesized in the tobacco plant root and moves up and accumulates in the leaves. If a tobacco stem is grafted to a tomato root, no nicotine appears in the tobacco leaves. Thus it may be possible to produce entirely nicotine-free tobacco, or on the other hand, force plants other than tobacco plants to produce nicotine.

Since drugs are notoriously active at very low concentrations, it was almost impossible to study their metabolism and mechanism of action prior to the advent of radioactive forms produced by biosynthesis. Most alkaloids are made in higher plants as a byproduct of metabolic processes. In order to label them with radioactive carbon 14, it was necessary to build special "isotope farms" which are small greenhouse-like structures wherein the plant may be grown for long periods of time in a radioactive atmosphere. Plants grown in this atmosphere at Argonne National Laboratory have been used to produce carbon 14 labeled alkaloids such as nicotine, ergotinine, ergotamine, reserpine, and many others. These compounds have been isolated and made available to various researchers in the United States for studies on localization in tissues, and metabolic breakdown in the body.

Techniques applicable to producing alkaloids also have been used to produce carbon 14 labeled vitamins, starches, fats, oils, sugars, essential oils (such as those found in the mint plant), rubber, proteins, and radioactive virus particles. These techniques now have been refined to the point that virtually any known biological compound can be produced and isolated. Isotopes other than carbon 14 also have been used, among them the stable and radioactive isotopes of hydrogen (H^2 and H^3), and the stable isotope of nitrogen (N 15). These have been used both alone and in combination to produce a doubly labeled compound which would trace the whole course of the metabolism of a compound. Cobalt 60 has been used to produce radioactive vitamin B 12 for diagnosing various diseases.

In addition to these gross syntheses, thousands of studies have been made concerning the pathways through which particular parts of a given compound are derived from its precursors. The isotope, particularly the radioactive one, has provided perhaps the most powerful tool known to man for discovering the innermost workings of the biochemistry of life.

FARM ANIMAL STUDIES

Nutrition of Farm Animals

By the use of radioisotopes, the metabolism of many elements in farm animals can be conveniently followed from their uptake in food in the form of elements and inorganic and organic compounds, through their uptake and incorporation into various regions of the body, and finally through their degradation and excretion. Tracer techniques are of extreme value in nutritional studies.

For example, an element which occurs in amounts of only a few parts per 100,000,000 parts of feed can be traced from the feed, through

the digestive tract, and finally to its location in the tissues of a 1,000-pound animal. All this can be done without interference with the normal physiology of the animal.

Many elements are required in small amounts by farm animals. A lack of cobalt in the diet decreases the formation of vitamin B_{12}. Tracer techniques also showed that high levels of molybdenum in cattle feed inhibit synthesis of vitamin B_{12}. Vitamin B_{12} labeled with cobalt 60 has been used for many types of investigation with farm animals. For example, vitamin B_{12} is transferred from the body of the cow to its milk during lactation, and the vitamin B_{12} content of milk may be used as an indication of the status of the cobalt nutrition. Vitamin B_{12} also is transferred from the hen to the egg. The vitamin desposited in the egg actually serves as the principal source for the chick up to several weeks after hatching. Even 12 weeks after hatching, the original vitamin in the egg represents an appreciable part of the total vitamin in the bird.

Sulfur is rapidly metabolized by animals. For example, the milk proteins of goats were found to contain radioactivity within three hours after the goats were fed sodium sulfate labeled with radioactive sulfur 35. Until recently it was thought that chickens could not use sulfur in the form of inorganic sulfate for synthesizing sulfur-containing organic compounds such as the amino acid cystine. Again, using radioactive sulfur, it has been possible to show that both hens and growing chicks can utilize inorganic sulfur. In fact, under certain conditions, the addition of sulfate to certain poultry feed increases the rate of chicken growth. The growth of cattle and sheep on a low-protein diet can be increased by feeding inorganic sulfur.

Isotope techniques have permitted important practical studies on the absorption and utilization of *calcium* from feed by farm animals. These studies are complicated by the loss of endogenous calcium from the blood through the intestinal wall into the feces. The availability of radioactive calcium 45 has made such studies much simpler. It has been shown, for example, that the level of endogenous calcium in feces changes appreciably with age, becoming progressively greater in older animals. Also, it has been shown that both calves and adult cattle can obtain large amounts of calcium from powdered limestone included in the feed. It was further found that calves could absorb and retain significantly more calcium from milk than from hay or grain. It appears that some dietary factors occur in milk which in some way promote absorption of calcium. Other tracer studies permit livestock feeders to get more efficiency from feed by more careful control of the calcium-phosphorus radio of the diet and by eliminating high concentrations of materials which adversely affect absorption of these elements.

The true digestibility of calcium also changes with physiological condition in cows and goats and the amount of uptake appears related to that needed for lactation, i.e., the lactating cow utilizes dietary calcium more efficiently than the nonlactating, and the pregnant cow more than the nonpregnant.

Studies have shown that most of the ingested calcium ends up in the skeletal system exchanging rather rapidly with the bone calcium so that only 40 percent of an injected dose remains in the blood after one minute. Apparently the mammary gland also stores calcium preceding parturition.

Calcium 45 administered orally to hens was transferred to the egg shell of an egg laid only 15 minutes after injection and some 35 percent was present in the shell of an egg laid 24 hours after injection. Calcium injected into albumen of fertile eggs showed that up to 10 days most of the calcium was derived from the yolk and only then was shell calcium used for embryonic development.

As indicated in the selected examples, radioactive tracer techniques have been of great importance in studying the mineral nutrition of farm animals. Tracer methods have been of perhaps even greater importance in studying the uptake and metabolism of *organic foodstuffs*. In the past, most of the detailed nutritional studies on animals were carried out with small laboratory mammals. Large farm animals have not been widely used because of the expense of purified diets. The use of tracer techniques, however, has permitted nutritional studies in livestock as well as in the smaller animals. For example, it is now known that the pig metabolizes the vitamin, nicotinic acid in the same way as the laboratory rat. This determination would have been difficult and costly using the classical chemical techniques, but by the use of carbon 14 labeled nicotonic acid the problem was much more easily solved. Similarly, studies with tagged compounds have been carried out with vitamin A, the lack of which sometimes produces impaired vision in cattle. Other tracer studies have led to techniques for correcting deficiencies in the amino acid methionine in dry plant livestock feeds by the addition of compounds such as chlorine and betaine.

Biochemistry of Body Processes in Farm Animals

In addition to more basic studies, radioisotope techniques have been of great benefit in studying biochemical processes in livestock. A few examples of recent work are described in this report.

Milk production.—A study of the biochemical functions of microorganisms which inhabit the stomachs of grazing animals may result in methods of controlling the chemical composition of milk. Grazing animals that chew their own cud (ruminants) depend for their existence on billions of bacteria and other microbes contained in the rumen (first compartment of the ruminant stomach). These microbes produce materials necessary to the life of ruminant animals. In this way, the tiny organisms are in effect a "fluid tissue" and are just as vital to the animal as the tissues of solid organs; i.e., the heart, liver, and kidneys. Once the role of this "fluid tissue" in manufacture of milk components is understood, as well as what the animal system does with products formed by the rumen bacteria, ways of controlling the type of milk produced by the ruminant may be possible. For example, milk low in fat might be obtainable directly from the cow, making unnecessary the mechanical processing to reduce fat content.

The ruminant is dependent upon a supply of fatty acids for its existence. These acids are the fermentation end-products of carbohydrates taken into the animal system in feed, such as hay. Some complex carbohydrates are manufactured and stored by the microbes in the rumen. The complex carbohydrates made by rumen microbes are called polysaccharides, which constitute a reserve source of energy for the microbes. It was found that this storage polysaccharide is chemically identical regardless of which of the various species of

microbes is involved in its production. And the same end-products, fatty acids, are formed from the storage polysaccharide as is formed from rapidly used external energy materials. This means the ruminant is assured of a continuous supply of the fatty acids upon which it depends.

Another point to reinforce the concept of the rumen microflora as a "fluid tissue" is that rumen microbes apparently all work toward the same end: they do not compete with one another and form antibiotics. They all carry out reactions necessary for their own life. This in turn results in the formation of substances vital to the life of the ruminant. Further study of the polysaccharide producing reaction could show the availability of carbohydrates contained in animal feed, and may demonstrate how rumen microbes behave in abnormal conditions.

Control of end-products formed by the rumen microflora may result in regulation of the chemical composition of milk. Scientists must first understand what substances go into manufacture of the milk component they want to control; and also must know what substances are produced from the various materials that the animal is fed. Once this is done, the principle of physiological control might be extended to include regulation of other animal products, such as proteins.

Effects of temperature.—Cattle breeds of temperate areas (such as the shorthorn) do very poorly in tropical areas. As environmental temperatures approach 80° F. food consumption, milk production, and growth rate begin to fall off, and at 100° F. these processes drop to perhaps one-quarter the ordinary values. It has been found that the thyroid secretory activity of cattle, as studied with radioactive iodine, showed a temperature dependence which paralleled the processes listed above. On the other hand, the thyroid activity of Zebu cattle (a tropical breed) was found to remain the same over a very wide environmental temperature range. Correlated with this, the food consumption and growth of these cattle is essentially independent of temperature. Basic studies of this type may some day permit the raising of high-productivity temperate zone cattle in tropical regions, perhaps as the result of appropriate hormone treatments.

An interesting application of the beta ray thickness gage was developed in connection with thyroid studies of cattle. In studies on the effects of temperature on cattle growth it is necessary to measure the hair growth and hair density of the animals since the hair is an important factor in heat loss processes. The usual methods are crude and unreliable. The absorption of beta rays by matter depends only on the weight per unit area of the absorber (provided that the average atomic number is relatively low). Therefore, using this principle, a hair-measuring beta gage has been developed to indicate directly the weight of hair per unit area. The gage consists of a source of beta radiation, thallium 204 or promethius 147, mounted on a thin rod attached to a mica window Geiger counter. The hair density is measured simply by moving the gage radiation source over the skin under the hair and the decrease in count is noted. The weight of the hair per unit area is determined from a calibration curve. Measurements of hair density made with the beta gage were compared with measurements made by weighing the hair clipped from a measured area. The hair density measurements by the beta gage required about half a minute, the precision is within about 5 percent.

In addition to the work on cattle, radioactive tracer studies on the thyroid glands of chickens also are being carried out. Advances in basic knowledge may lead to more efficient production of meat and eggs. The thyroid gland of chickens, like that of higher animals, secretes a hormone that plays an important role in regulating metabolism (the rate at which body tissues oxidize food to produce heat and other forms of energy). Because of its basic function, thyroid hormone affects such economically important traits in the chicken as growth rate, feathering, efficiency of conversion of feed into meat and eggs, and reproduction (fertility and rate at which eggs are hatched).

Iodine in animal blood streams becomes concentrated in the thyroid gland, located in the throat. The gland in turn uses the iodine to produce thyroid hormone. Research workers use radio-iodine, chemically identical to the stable variety, to "tag" hormone being released to the blood with radioactive atoms, and follow the substance in the system by means of sensitive detecting devices. In this way, they are able to measure the secretion rate of thyroid hormone and discern the forms it takes in the thyroid gland and blood stream.

Apparently two different chemical forms of thyroid hormone occur in chickens: thyroxine and triiodothyronine. If large doses of radio-iodine are administered, the thyroid gland is destroyed. This permits determining the effects of thyroid hormone deficiency in chickens. Among the immediately apparent effects are poor growth and feathering.

Thyroid hormone does not function in the fowl exactly as it does in mammals. For example, blood-protein bound iodine, a valuable index of the thyroid state in mammals, is very low in chickens, and is not useful as a criterion of thyroid activity. Also, triiodothyronine is more potent than thyroxine as a goiter preventive in mammals, but not in chickens. Although much is known about thyroid functions in chickens, more fundamental information is needed to alter or control thyroid state for practical advantage in poultry production. More information also is needed to increase basic biological knowledge about differences in thyroid physiology between birds and mammals.

LETTER REQUEST TO DEPARTMENT OF AGRICULTURE

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Accordingly, it would be deeply appreciated if the Department of Agriculture could prepare a brief letter report of its programs in the peaceful uses of atomic energy.

Reports of this nature have been furnished by the Atomic Energy Commission, which has suggested that your Department be contacted for information concerning programs which are not operated under the principal direction of the AEC.

The background reports contained in Volume II of the Report of the Panel on the Peaceful Uses of Atomic Energy provide a useful guideline for the information being sought in connection with the present study. * * *

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CONTRIBUTION OF ATOMIC ENERGY TO AGRICULTURE BY THE DEPARTMENT OF AGRICULTURE

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The major contribution of atomic energy to agriculture is through the use of its byproducts, radioisotopes and radiation in agricultural research. The wide application of materials and techniques and their importance in this field has been presented in the Background Material, Vol. 11, page 161, Report of the Panel on the Impact of the Peaceful Uses of Atomic Energy to the Joint Committee on Atomic Energy, January 1956. This broad picture has not altered significantly and will not be reviewed in this communication.

In the direct application of radiation, studies in plant breeding and pathogen mutation have been markedly stimulated by the availability of radioactive cobalt and cesium sources.

The success of the screw worm eradication program in the southeastern United States has led to a substantial increase in basic research on the effects of radiation on insects.

Extension of this "sterile male" technique to two species of fruit flies will enter the field test phase on some Pacific islands within the next few months. This is a more difficult operation than the screw worm eradication since these important plant pests mate repeatedly and have a much longer adult life.

The increase fundamental research on the effects of radiation on the biodynamics, physiology, and biochemistry of insects should lead to the application of this technique to other insects and, through a better understanding of the components and processes involved, perhaps to other more simple and less costly means of attaining the same end.

The principal research program on the radiation sterilization of food under the Research and Development Division, U. S. Army, has been recently curtailed. You are referred to the Ad Hoc Panel Report to the Interdepartmental Committee on the Radiation Preservation of Food (February 1960) for the current picture of the civilian program. This document mentions briefly two areas of active Departmental interest: first, the low dose treatment of fresh produce and fruits for the supression of microbial damage during transportation and storage; second, the even lower dose treatment of certain fruits to permit their movement through insect quarantine barriers. The recent amendment to the Food, Drug and Cosmetic Act has emphasized the need for basic research on the effects of irradiation and the characterization of the byproducts of such treatment.

As indicated in the 1956 report cited earlier, the most important contribution of atomic energy to date is through the wide use of radioisotopes in "tracer technique" applications. Work in the various fields describe in the report is generally increasing.

In entomology, for example, an increasing number of compounds of interest are being "tagged" with radioactive carbon or phosphorus and are giving important information not otherwise available on the mechanism of the development of resistance to and the detoxification of these compounds in the insect. Further, this procedure often is the valuable means of evaluating the residue, in character and quantity, in meat, milk and crops.

The availability of tritium has stimulated work on all phases of the efficient use of our water resources, from laboratory studies on the movement of water in crop plants to field studies on the drainage and replenishment of underground stocks.

This year the Department has initiated a project on the removal of fission products from milk. The annual cost of this work, estimated to be $240,000, is shared equally by the Atomic Energy Commission, the Public Health Service, and the Department of Agriculture. Attention at present is focused on the removal of Strontium 90 by ion exchange methods, but the work will include iodine 131, as well as the apparently less important elements, Cesium 137, Strontium 89, and Barium 140. Although earlier studies indicate that exchange resins may be very effective, much work is required to develop a workable process, the product of which will be free from objectionable flavors and nutritionally equivalent to the original milk.

During the past two years the Department has undertaken, in addition to the laboratory and field work on the uptake of fission products, an investigation of the possibilities for the decontamination of crop lands.

There has been no development which affects the general appraisal, made in the 1956 report, of possible economic effects.

A concrete example of economic contribution, however, may be added. Losses to livestock in the southeastern United States, attributable to schew worm infestation, have been estimated to average over $10 million per year since about 1935. From the winter of 1957 to date losses have been negligible, the insect having been eliminated at a cost of approximately $7 million.

It is our hope that a well-rounded research program, both public and private, utilizing these new tools to the fullest extent, will make possible additional economic advances.

COMMUNICATION FROM ATOMIC ENERGY COMMISSION

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One of the specific items mentioned by you was a report on the status and prospects in the development of food preservation by irradiation.

The Department of the Army has the primary responsibility to date for the conduct of the irradiation preservation of foods program in the U.S. It is suggested, therefore, that you request a report on this subject from Mr. Richard S. Morse, Director of Research and Development, Office of the Secretary of the Army.

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LETTER OF REQUEST TO DEPARTMENT OF THE ARMY

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Accordingly, it would be deeply appreciated if the Department of the Army could prepare a brief letter report of its program concerning the radiation preservation of food.

Reports of this nature have been furnished by the Atomic Energy Commission, which has suggested that your Department be contacted for information concerning programs which are not operated under the principal direction of the AEC.

The background reports contained in Volume II of the Report of the Panel on the Peaceful Uses of Atomic Energy provide a useful guideline for the information being sought in connection with the present study.

RADIATION PRESERVATION OF FOOD BY THE DEPARTMENT OF THE ARMY

The Department of the Army welcomes the opportunity offered, in your letter to me of 24 February 1960, to present a report on the current status of its program on the radiation preservation of food.

On 14 January 1960, I appeared before the Joint Congressional Committee on Atomic Energy of the Congress. At that time I explained that on the basis of an investigation of the Army's Food Irradiation Program, which I conducted shortly after assuming my present office, I had suggested to the Chief of Staff, United States Army, that action be taken to suspend the construction of a proposed pilot plant and reorient the program toward fundamental research. My action was based on the knowledge that certain complex unsolved fundamental research problems remained to be resolved before the Army was ready to initiate a pilot plant or developmental phase. These problems were in the general areas of wholesomeness and toxicity, packaging, microbiology, biochemistry, organoleptic and enzymatic changes. Additionally, there were questions concerning the military logistics and applications factors related to irradiated foods on which I felt we should have more definitive answers before progressing to more advanced stages of the program. Subsequently, the Chief of Staff of the Army informed me that the Quartermaster General had been directed to suspend construction of the proposed pilot plant, and that the Quartermaster General would prepare and submit for approval a revised research program as I suggested.

I am forwarding, as Inclosure 1, copies of the revised reoriented Army Irradiated Food Program which I have recently approved. Some matters relative to the funding of this revised program have not been resolved.

This revised program calls for the expenditure of $5,130 million of research over a six year period. The research is to be conducted under seven major task headings: military applications and economic analyses; assurance of wholesomeness; pre and post irradiation studies; destruction of microorganisms; nuclear effects on foods; acceptance testing; and packaging studies. Integral to the program is the requirement for the construction of a radiation research facility consisting of a variable voltage 1–12 M.E.V. (million electron volt) linear electron accelerator; a one million curie Cobalt–60 gamma radiation instrument; and minimal associated food preparation and laboratory facilities. An interdepartmental board is to be appointed to make recommendations concerning an appropriate site for this research facility. Prime consideration will be given to the feasibility of locating this facility at the present site of the Quartermaster Research and Engineering Center, Natick, Massachusetts.

At Inclosure 2 you will find background material suporting the Army revised research program, Inclosure 1. This material should be helpful to your staff in up-dating Chapter 6, Volume II of your 1956 report.

At Inclosure 3, I have provided you with all of the detailed correspondence and statistical information now available on the current status of wholesomeness studies on irradiated food being conducted by The Surgeon General of the Army as a contractor to the Quartermaster General of the Army. To date, no food has been submitted for clearance to the Food and Drug Administration for routine feeding to the military or civilian population. While some phases of this extensive effort involving approximately 250,000 animals are completed, it will be December 1963 or later before the final overall results of the study will be known. This is the estimated date by which all investigators will have completed their individual studies, submitted their final reports to The Surgeon General for evaluation and their histopathology specimens and reports to the Armed Forces Institute of Pathology for IBM coding and evaluation. In the course of certain of the investigations to date, abnormalities have been observed in some test animals. Certain of these abnormalities have been adequately explained (e.g., blindness noted in rats was due to heredity and certain tissue enzyme changes were due to vitamin deficiency). Other abnormalities noted have not as yet been adequately explained and appear to be due to the irradiation process. Additional studies have been initiated to seek the answers to the remaining unexplained anomalies. While it cannot be predicted with certainty that satisfactory answers will be obtained to these problems, expert scientific opinion considers that the research should continue.

A possible corollary to the new revised Army program is the proposed National Civilian Radiation Processed Foods Program currently under consideration by the Interdepartmental Committee on Radiation Preservation of Food. If implemented as proposed, this civilian program would complement the Army's program. The civilian program would concentrate on the low dose (pasteurization) treatment of foods as opposed to the revised Army program which stresses research on the high dose (sterilization) treatment of foods.

The original Army program, while emphasizing research in high dose treatment of foods, did not neglect the technique of low dose treatment. Likewise, in the revised Army program major attention is placed on sterilization techniques without, however, sacrificing necesary effort on the pasteurization technique applicable to foods of major military significance. As the proposed civilian program states, these two areas are complementary. Certain of the problems encountered in the high dose area must be solved satisfactorily before complete success can be realized in the low dose treatment area. The more difficult problems appear to be in the area of high dose treatment. It seems entirely logical, therefore, to place prime emphasis in the revised Army research program on the solution of these more complicated problems.

The Army will continue to make major contributions to the fund of available basic knowledge which will ultimately make possible the final determination concerning the role of radiation preserved foods in the national and international economies.

The Army welcomes any and all assistance in this effort. We are particularly pleased that the member agencies of the Interdepartmental Committee on Radiation Preservation of Food have seen fit to participate more actively in the advancement of the national program which the Army is spearheading. The broadening of the national research base in the radiation preservation of foods field is an important step which will most certainly facilitate our objective of early transition to industry.

* * * * * * *

STAFF NOTE.—A great deal of background information on radiation preservation of food has been printed by the Joint Committee on Atomic Energy, in connection with hearings on the National Food Irradiation Research Program held on January 14 and 15, 1960. The following report, Revised Army Program: Food Preservation by Ionizing Energy, appeared subsequent to these hearings.

REVISED ARMY PROGRAM

ON

FOOD PRESERVATION BY IONIZING ENERGY

Approved: 11 March 1960

Department of the Army
Office of The Quartermaster General
Washington 25, D. C.

1951

REVISED ARMY PROGRAM

ON

FOOD PRESERVATION BY IONIZING ENERGY

Approved: 11 March 1960

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Washington 25, D. C.

1961

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I. POLICY

Inasmuch as nonmilitary departments are beginning to be in a position of carrying leadership responsibilities for the national Atoms-for-Peace Program in radiation processing of foods, the Army will affect a smooth transition toward focussing on military requirements. Research will be directed toward the objective of procurement from the civilian economy of the first generation of a relatively few food items of important military significance. The developmental lead time will be compressed to the maximum extent feasible, consistent with the state of the art and the requirement for the prior orderly resolution of the key unsolved fundamental research problems. The Army will work closely with industry during the research stage with the objective of facilitating the earliest possible transition to process engineering and production.

Inasmuch as the Army's activity will continue to serve as the backbone of the Nation's effort in this program area, generous collaboration will be extended to other organizations in the joint advancement of the President's Atoms-for-Peace Program.

Inasmuch as an adequate civilian production base is required before military subsistence requirements can be met, cooperation with American industry will be encouraged. Furthermore, information will be disseminated as widely as feasible in order to increase technical know-how in this country.

II. SIX-YEAR OBJECTIVES

1. To obtain wholesomeness clearances permitting unrestricted use of foods preserved by ionizing energy.

2. To conduct the necessary basic research to advance the technology of food radiation processing so that items of military significance and of quality far superior to analogous items available in the combat theatre can be procured:

   a. Primary emphasis to be placed on high dose treated (sterilized) pork, smoked ham, chicken, and beef.

   b. Secondary emphasis to be placed on those low dose treated (pasteurized) items of special military significance.

3. To conduct timely economic analyses.

4. To formulate such items into logistic-saving components for use in Army ration systems from those in the support areas to and including individual military feeding in the forward areas.

5. To develop components meeting special requirements of the Navy, Air Force, and Marines.

6. To develop process engineering data for efficient transition into industrial sponsorship.

7. To determine, within the coming 3 years, whether the transition pilot-production plant will be built by industry, the Atomic Energy Commission, the Army or another organization, and to effect the necessary transfer of relevant know-how.

8. To establish a reservoir of basic information for future improvement of radiation processed foods.

III. RESEARCH AND ENGINEERING PHASES

The program will be channelled essentially into the following tasks: Military applications and economic analysis, Assurance of wholesomeness, Pre and Post Irradiation Studies, Destruction of microorganisms, Nuclear effects on foods, Acceptance testing, and Packaging studies.

Prime interest will be focussed on four sterilized meats and their combat ration formulations. Secondary attention will be devoted to low dose treatment (pasteurization) of fresh fruits of high morale value. A description of the seven tasks is given below. The starting point in each of these tasks is the present state of the art. At the same time, they have been pointed directly toward the immediate six-year military objectives, delineated in Section II.

1. Military applications and economic analysis.

Attention will be devoted toward completing a comprehensive operations analysis to determine the logistic, operational and economic aspects of incorporating radiation processed foods into the combat feeding system of the armed forces. The studies will consider both limited and general warfare. Comparisons will be made between foods preserved by radiation and by other processes, together with the respective roles to be played by each in the optimum overall combat feeding system.

2. Assurance of wholesomeness.

This phase will continue to be directed by The Surgeon General and logistically supported by the Quartermaster Corps. The protocol under which the work is to be continued has been developed with full cooperation and concurrence of the Food and Drug Administration. It has been designed to result in clearances for unrestricted consumption of radiation processed foods by both military and civilian populations. Included are six principal sub-phases, namely:

a. Short term feeding to animals, principally rats, which has been completed.

b. Long term feeding of 21 representative foods to each of 2 species of animals for 2 years, followed by comprehensive histopathological examinations. The feeding work is 90 per cent completed. The tissue evaluations, which will be done by the Armed Forces Institute of Pathology, are currently in progress.

c. Carcinogenicity and enzyme studies which are approximately 50 per cent completed.

d. The resolution of several experimental anomalies, which have been noted in long-term animal feeding. These will require effort beyond that already in progress. Additional work in two areas, possible sterility in dogs and possible auricular rupture in mice, may extend over a period of 3 years.

e. Additional new work with regard to the biological aspects of possibly induced radioactivity.

f. Human feeding studies. Those conducted for evaluation of acceptability of radiation processed foods have been deferred pending the determination of residual induced radioactivity. It appears that the tests may be resumed in the not too distant future. Long-term human feeding will await adequate resolution of the animal anomalies and conclusive information on induced radioactivity.

3. Pre and Post Irradiation Studies

Efforts will be directed toward meeting requirements of field Army feeding. Usable sterilized beef, pork, chicken, and ham items in the individual combat meal and small group operational rations will be developed in accordance with Combat Developments Objectives Guide. In addition, the use of these prime components, either sterilized or pasteurized, as logistic-saving components in A and bulk B rations will be pursued. Morale-significant items, such as fresh fruits, will constitute a tertiary goal.

Processed foods will be studied with regard to their retention of color, flavor, texture, and nutritional quality. Pre-irradiation and post-irradiation factors will be considered, in addition to those acting during the exposure period. Interactions among these factors will also be taken into account.

Pre-irradiation processing treatments which will be investigated will include pre-cooking techniques such as steaming, roasting, broiling, and frying; time, temperature and method of heat application for enzyme inactivation; addition of salts, tenderizers, flavor accentuators, spices, and off-flavor suppressants; headspace composition; and oxygen odor scavengers.

The effects of processing conditions accompanying irradiation will be explored. Among those which may have significant influence on product quality are dose rate, dose fractionation, product temperature, and gaseous exchange.

Among the post-irradiation factors which will be studied are: the influence of residual enzyme activity, cause of excessive softening, time-temperature condition conducive to product improvement,

interactions between various components of formulated products, interaction between food and package, and time-temperature effect on general chemical degradation of stored irradiated foods.

A fundamental research program will be continued to determine the origin of the organoleptic changes, the mechanisms whereby they occur, and means for their control. Initially, this sub-phase will be focussed principally on beef.

Studies will be conducted on identification of chemical changes occurring during the irradiation of meats, and subsequent storage under a variety of time and temperature, dose, dose rate, headspace composition, and additives.* Fractionated meat components and model systems of proteins and lipids will be studied to provide an understanding of the underlying reactions.

Optimum characteristics of odor scavengers, which are effective in "dry" packs, will be established. Further research will be undertaken to develop scavenger systems which can be effectively utilized with "wet" packs.

The mechanism of proteolytic enzyme reaction will be studied, with the hope of improving methods of enzyme control, superior to the present blanching technique.

4. Destruction of microorganisms.

Basic research will be conducted on the physiology and biochemistry of microorganisms with special emphasis on anaerobic spore formers of public health significance. The mechanism of action of ionizing energy on the various stages of development of these microorganisms will be determined.

A clear understanding of the influence of a variety of processing and substrate factors will be sought in order to develop conditions whereby foods can be safely irradiated at substantially lower doses then presently adopted to gain quality and economic advantages. Some of the processing factors will include: dose, dose rate, dwell time, beam spectra, heat-interaction, energy pulsing, and temperature. Some of the substrate factors to be analyzed are: type of food, moisture, pH, strength of inoculum, and chemicals.

Studies to determine the particular types and strains of Clostridium botulinum which are the most radioresistant will be undertaken in order to establish a definitive sterility reference for processing by ionizing energy.

*Usual sense of the term, not legal sense.

5. Nuclear effects on foods.

The pertinent isotopic content of selected foods of interest will be determined by literature analysis and experimentation. Efforts will be expanded to determine the probability and theoretical and measurable amounts of activity induced in actual food items and in food "phantoms" by radioisotope, spent fuel rod, and electron beams of various energies.

A quality control procedure will be developed, which will be used to guarantee radiological safety of treated foods as established by Food and Drug Administration, Public Health, Atomic Energy Commission, and the Army Surgeon General, leading to early resumption of human feedings studies and eventual general acceptance of food so processed.

The above studies will be coordinated with The Surgeon General, particularly with reference to biological interpretations of the resulting data.

6. Acceptance testing.

Troop-feeding tests will be conducted on two levels following approval by and with the collaboration of The Surgeon General. The first, designed to determine acceptability, consists of single meals to about 200 soldiers per test. The second, designed to measure monotony factors and field utilization, will be operated as engineering tests.

An engineering test will be based upon 100,000 meals containing about 5.5 oz of irradiated meat per meal. About 2 to 4 engineering tests per year will be conducted, once the approved irradiated items can be provided.

7. Packaging studies.

Only minor studies will be conducted on tin plate cans, which have been shown to meet minimum requirements as a container for irradiated foods. Extended storage involving aluminum cans will be completed.

Investigations on flexible and semi-rigid containers will be directed toward materials and container research. An evaluation will be made of the nature and amount of extractives and possible induced radioactivity produced in various plastics by the irradiation process. Means of controlling the production of these substances will be sought. Work will be directed toward the development of new laminates with improved resistance to ionizing energy, in addition to the normal attributes of useful containers.

IV. TECHNICAL COORDINATION WITH OTHER ORGANIZATIONS

Within the Army, CONARC, CDEC, and other elements will be consulted in the conduct of operational analyses of irradiated foods in the Army subsistence complex. Additionally, collaboration will be maintained with the Navy, Air Force, and Marine Corps in meeting their special requirements.

Coordination with other government agencies and the Interdepartmental Committee on Radiation Preservation of Foods will be effected. Intimate bilateral working relations will be maintained especially with the Atomic Energy Commission, the Department of Health, Education and Welfare, the Department of Agriculture, the Department of Interior, and the National Bureau of Standards on special work phases of mutual interest.

Advice will be sought from various quasi-governmental bodies, such as the National Research Council.

The major portion of the actual research itself will be conducted by private industry and universities, although irradiation services from central sources will be provided. The plans and results of all workers in the program will be closely coordinated.

V. FACILITIES

Maximum use will be made of facilities available in industrial and academic institutions, in addition to those currently present in government establishments. The state of progress in the program is advancing at such a pace and in such a direction, however, that a moderate research facility is now needed to carry out necessary investigations.

The most desirable source from the standpoint of radio-logical safety is cobalt-60. The availability of such a source as soon as practicable is essential for major advances in the program, particularly in the human feeding phases. At the present time, adequate sources of cobalt-60 are not available. Based on an Army research requirement 2 years hence of about 50 tons of gamma-treated food per year; of a reasonable source time for research on such problems as source geometry, dose distribution in containers of different sizes and shapes, and flux uniformity of radiation field; for use by other Government agencies; and for irradiation services to industrial collaborators, it is estimated that about a megacurie of cobalt-60 will be required.

In order to provide the minimum amount of laboratory support, a small food sampling, preparation, and testing annex will be needed as an adjunct to the gamma facility.

The requirement for a source of electrons at the same location has been carefully considered, in view of the availability of a partially completed linear accelerator. There are good grounds to believe that future costs of commercial processing may favor electrons significantly over radioisotopes for some commodities. Certain treatments, such as restricted surface irradiations, can only be carried out with electrons of specified energies. It is desirable, on this basis, that electrons continue to be investigated.

The actual cost of the needed research facility, currently proposed to be constructed at QM R&D Command, cannot be determined without negotiations with potential contractors. Estimates are as follows: Cobalt-60 Irradiator, (1,000,000 curie) $1,100,000; completion of linear accelerator (12 MEV), $400,000; Food laboratory annex $300,000. Total estimated cost amounts to $1,800,000.

Current analysis indicates that the most suitable location of this research facility is at the Quartermaster Research and Engineering Center at Natick, Mass., where it can be utilized, not only for food research, but for other research requirements of the Army, other DOD elements, and the national civilian radiation foods program. However, a Joint Board will be formed by the Quartermaster General, composed of representatives of agencies most concerned with the location, for the purpose of recommending to the Chief of Research and Development the most appropriate location for the facility.

VI. FUNDING

The required funding is shown in Table I. It is to be noted that the Atomic Energy Commission has an unexpended balance of approximately $2,100,000 as of this date. This money can be applied toward certain phases of the project funding, if approval is granted.

Breakdown of the figures follow the work phases described in Section III. The last entry covers the cost of radiation services furnished the various research contractors. The cost of food for troop testing is not included in this budget.

Table I

RESEARCH AND DEVELOPMENT BUDGET

FISCAL YEAR	61	62	63	64	65	66
Military [illegible] economic analysis	--	--	--	--	50,000	--
Assurance of wholesomeness	300,000	250,000	200,000	100,000	50,000	50,000
Pre and Post Irradiation Studies	340,000	340,000	340,000	440,000	320,000	250,000
Destruction of microorganism	90,000	80,000	60,000	50,000	25,000	25,000
Nuclear effects on foods	40,000	40,000	40,000	40,000	--	--
Acceptance testing	--	--	--	35,000	60,000	60,000
Packaging studies	50,000	50,000	50,000	100,000	75,000	50,000
Radiation services	180,000	180,000	180,000	180,000	180,000	180,000
TOTAL	1,000,000	940,000	870,000	945,000	760,000	615,000

FACILITY BUDGET FY '61*

Food Preparation Facility	$ 300,000
Electron Accelerator	400,000
Cobalt-60 Irradiator	1,100,000
Total	$1,800,000

*Can be funded from AEC unexpended R&D funds

IMPACT OF RADIOISOTOPES ON MEDICAL DIAGNOSIS AND THERAPY

By the U.S. Atomic Energy Commission

CONTENTS

Medical Diagnosis.
- Blood Volume Studies.
- Water Volume.
- Cardiac Output.
- Peripheral Cardiac Disorders.
- Thyroid Disorders.
- Other Diagnostic Applications.
- Localization of Tumors.

Medical Therapy.
- Selective Absorption.
- Differential Turnover.
- Treatment with Colloids.
- Intravenous Injection and Clearance.
- Intracavity Insertion.
- Interstitial Implantation.
- Topical Applications.
- Ophthalmic Applicators.
- Teletherapy.
- Use of Accelerators and Reactors.

Impact of Radioisotopes on Medical Diagnosis and Therapy[1]

Almost 25 years have passed since a manmade radioisotope first was used to treat a disease of man—phosphorus 32 in the blood diseases, leukemia and polycythemia vera. In that interval, nuclear medicine has come of age. Some indications of this progress are the establishment of The American Society of Nuclear Medicine, the founding of the journal, Minerva Nucleare, the publication of a number of monographic textbooks, and the training required in nuclear medicine for specialty certification after 1960 by the American College of Radiology. This growth has been helped tremendously by the variety and volume of artificial radioisotopes produced by reactors.

The Commission's administration of the Atomic Energy Acts of 1946 and 1954 restricted the distribution and sale of radioactive isotopes to physicians who were qualified to use them properly. The net result is confidence in radioactive therapy and diagnosis, and a body of discriminating physicians using radioisotopes in the clinic for the benefit of the patient.

In 1946, when clinically useful amounts of radioisotopes became available, there was a considerable backlog of basic biomedical data which could be directly applied to the study of disease in man through the use of appropriate radioisotopes. During the past decade, medicine has made exceptional advances which were uniquely dependent on radioisotopes, and undoubtedly will make many more in the future. However, because the backlog of basic biomedical data is about exhausted, the character of future research, and probably of the advances as well, may be expected to be different. The ultimate use of radioisotopes may well be to study the kinetics of subtle biochemical reac-

[1] Reference: "Radioisotopes in Medicine," SRIA–13, Richard R. Tarrice and Mark S. Blumberg, M.D. (Stanford Research Institute, Menlo Park, Calif.) November 1959. 186 pages. Available from Office of Technical Services, U.S. Department of Commerce, Washington 25, D.C., price $3.00.

tions in the body roughly by such techniques as now are employed when thyroid function is measured by iodine uptake.

The Commission will continue to direct its efforts toward accelerating the sound development and use of radioisotopes in biochemical research and medicine.

This report's evaluation as regards clinical use of radioisotopes takes into account two precepts:

(*a*) Unnecessary exposure of a patient to irradiation is undesirable, and the benefits to the patient of a diagnostic or therapeutic procedure using radioactivity must be measured against both the potential and direct biological effects of the irradiation.

(*b*) With a few notable exceptions, a procedure using a radioisotope is but one of several alternative procedures available to the physician in dealing with a specific clinical problem and the physician must choose that which is best suited to the case at hand.

The following summaries indicate which isotope procedures are generally considered to offer definite medical benefits.

MEDICAL DIAGNOSIS

Knowledge gained by the use of radioisotopes in medical diagnosis, and in related fundamental studies, has expanded steadily since reactor-produced radioisotopes first were made available in quantity. Only the more important medical diagnostic applications of isotopes are described in this report.

Blood Volume Studies

Red blood cells first were tagged isotopically with phosphorus 32 produced in the cyclotron. Simpler techniques since have been developed for measurement of plasma and red cell volume using human serum albumin labeled with radioactive iodine 131, or chromium 51. The chromium 51 label is more stable biologically than is phosphorus 32 and since chromium 51 emits gamma rays, it can be counted readily in a well-type scintillation counter. Potassium 42 and thorium B also have been used to tag red blood cells. Plasma volumes are measured by radioactive iodinated human serum albumin, and unlike the dye technique, this method is not interfered with by fatty substances present in the liver or by hemolysis—the escape of hemoglobin from destroyed red blood cells.

Water Volume

Investigations in fundamental biological research often have led to development of clinically useful procedures. Dynamics of water metabolism and changes in total body water in various diseases could not be studied satisfactorily until techniques for use of isotopic water were developed. Earlier work with the stable isotope, deuterium, has been superseded by the radioactive isotope of hydrogen, tritium, which is more easily measured.

In the formation of ascites (abnormal fluid in the peritoneal cavity) a large and rapid interchange of water between the ascitic fluid with the blood plasma has been demonstrated. Studies with radioiodinated albumin have shown that the protein in ascitic fluid is in equilibrium with plasma proteins.

Another approach to quantitative estimation of body composition is through activation analysis. Radioactivity is induced in certain elements of blood or other biological material by exposing them to thermal neutrons in a reactor. By analysis of the radioactivity induced, the amount of an element present can be measured. This method has been used to demonstrate trace amounts of gold in blood, to measure iodine in the thyroid, to analyze sodium and potassium in muscle, and to measure amounts of cobalt, iron, and zinc in other human material. The sensitivity of this method is much greater than microchemical techniques for many elements.

Cardiac Output

Albumin labeled with iodine 131 has been adapted for measuring quantitatively the output of the heart. An important advantage of this method is the fact that albumin remains in the circulation for comparatively long periods of time as contrasted with the use of freely diffusible radioactive elements. The radio-iodinated albumin method is possible through use of highly sensitive detection apparatus. Cardiac output is determined by establishing a general dilution curve after iodine 131 is first introduced into the vascular system. Agreement with other methods of direct measurements in man is within 10 percent.

Peripheral Cardiac Disorders

Radioactive sodium has been much used in studies of peripheral vascular flow in man to measure either circulation time or efficiency. The tagged albumin method also is applicable to determination of peripheral flow. Liver blood flow can be determined by measuring rate of disappearance of colloidal chromic radiophosphate from the blood stream. Various radio-colloids, such as heat-denatured albumin and gold, are similarly used.

Thyroid Disorders

By far, the most widely used radioisotope in medical practice is iodine 131. Its principal diagnostic use is to measure the functional state of the thyroid gland. Numerous tests have been proposed, but all depend on the thyroid gland's uptake of iodine, or the fact that the iodine not concentrated in the gland is excreted by the kidneys. The simplest and most reliable tests are 6-, 8-, or 24-hour thyroid uptakes. Clear diagnosis may be obscured at times by overlapping of the range of values in hypothyroidism or hyperthyroidism and normal function of this gland. The true functional state is usually revealed by doing double tests.

Another radiosotope of iodine, iodine 132, is of interest in studying thyroid function. It has a shorter half-life than iodine 131 (2.33 hours as compared to 8 days) and a more energetic emission. From the important standpoint of minimizing accumulated radiation dosage to the patient, the shorter half-life far outweighs the greater energy. When iodine 132 is used instead of iodine 131 at equivalent dose levels, thyroid radiation is reduced by a factor of 30, and the total body dose by a factor of at least 15. This is particularly important for pregnant women and in children.

Other Diagnostic Applications

Radioactive vitamin B_{12} labeled with cobalt 60 is used in the diagnosis of pernicious anemia and other macrocytic anemia. External measurement of liver radioactivity after the patient has ingested radioactive vitamin B_{12} permits accurate determination of the degree of vitamin B_{12} absorption and diagnosis of an early or typical case of pernicious anemia as well as the more easily detected severe cases.

A test using radiovitamin B_{12} is being developed for measuring liver cell damage in hepatitis.

Diodrast has been used extensively in its stable form in X-ray diagnosis to measure specific kidney functions and Rose Bengal has been used similarly in liver tests. Employment of tracer quantities of Rose Bengal or Diodrast labeled with radioiodine permits measurement of the functioning of the kidneys and liver with gamma-ray scintillation probes and radiation counting equipment.

Localization of Tumors

During the last 10 years, considerable research has dealt with use of radioisotopes in the delineation of various types of cancer. The localization of cerebral tumors, using isotopes, has been investigated by several groups in this country as well as abroad.

Studies have indicated that the endothelial blood-brain barrier which prevents migration of certain ions from blood plasma into the brain tissue is altered somewhat at the site of a rapidly growing tumor. The intravenous injection of a radioisotope results in an increased radioactivity at the tumor surface. Although the difference in count rates is not very high, a ratio of 7 to 1 or even 10 to 1 is frequently obtained.

In 1948, a procedure was developed for the localization of brain tumors by injecting iodine 131 labeled di-iodofluorescein intravenously followed by count rates of the head. Other workers have used iodine 131 labeled sodium iodide and iodinated human serum albumin. Although several types of instruments have been devised for measuring radioactivity in such circumstances, a more recent device is made up of a heavily shielded scintiscanner with a pulse-height analyzer which helps to increase the contrast between normal and tumor tissue.

The use of positron emitting isotopes (arsenic 74 and copper 64) for injection resulted in a further increase in contrast. These isotopes emit positrons (positive electrons) during decay and these particles interact with electrons in absorbing substances, producing two gamma photons per positron-electron collision. The gamma photons have the same special orientations: they are emitted in exactly opposite directions. This technique was used and later improved upon considerably. This instrument consists of two scintillation containers with very narrow collimators plus a coincidence counting circuit. The patient's head is placed between the two containers and a plot is made of the area scanned. This particular technique has proved quite successful in the localization of certain intracranial lesions.

Brain tumor localization also has been studied using phosphorus 32, a pure emitter of short-range beta rays, but in this instance the counting must be done within the skull during surgery. A highly sensitive needle-like Geiger counter has been developed which has been success-

ful in locating brain tumors. The patient is given a tracer dose of phosphorus 32 prior to the operation and, at surgery, the counter is used to delineate the margins of the tumor, assisting the surgeon to remove the mass completely.

Another practical application of an isotope for tumor localization has been the use of phosphorus 32 in diagnosis of intraocular (eye) tumors. In cases of suspected melanoma (pigmented tumor), the intravenous injection of phosphorus 32 has resulted in a higher count rate over the tumor as opposed to the count rate of a normal area of the eye. Although negative uptake of a suspicious area does not rule out melanoma, the use of this isotope is of considerable importance to the opthalmologist.

MEDICAL THERAPY

Selective Absorption

The use of radioisotopes in direct treatment of cancer requires that the diseased tissues take up a specific radioelement and localize it in sufficient concentration for its radiation to inhibit or destroy the cancer. At the same time, the concentration of radioactive material in normal tissue should be relatively low. The radiation emitted by the isotope should preferably be of short-range, such as a beta particle which travels only a few millimeters in tissue. However, except for the concentration of radioiodine isotopes by thyroid tissue for the treatment of hyperthyroidism, or a few special cases of functional thyroid cancer, selective localization has not been achieved. Attempts to produce antibodies against tumor tissues which may carry radioactivity to a tumor show considerable promise and offer hope for the future.

Iodine 131 has been in use for over 15 years as a treatment for hyperthyroidism. Many thousands of patients have been treated, and a large number of reports have been published summarizing the experiences of many institutions. There is general agreement that iodine 131 therapy is effective, safe and relatively simple. However, its use is restricted in simple hyperthyroidism to patients over 40 years of age in order to avoid increasing the risk that the radiation might contribute to thyroid cancer and leukemia.

First reports were overly optimistic in the results of treating thyroid tumor metastases—cancer originating in the thyroid but growing elsewhere in the body. Only a small fraction of thyroid carcinomas (about 15 percent) concentrate enough iodine 131 to deliver a useful radiation dose to the gland or the metastases. At the present time, the majority of thyroid carcinomas are treated by surgery and/or external radiation.

Radioiodine also has been used in the treatment of severe *angina pectoris* and congestive heart failure which has not responded to conventional medical therapy. By reducing the activity of the thyroid and consequently the metabolic needs of the body, the work of the heart is reduced and the damaged blood vessels or muscles then are better able to meet the circulatory requirements of the patient.

Differential Turnover

Although a radioelement may not localize strongly, the rate of accumulation or turnover by a specific organ or tissue may be sufficiently different from that in other organs or tissues to establish a basis

for a useful therapeutic effect. The first disease to be treated successfully with an artificially produced radioisotope was polycythemia vera, a disease of the red blood cells.

Research showed that tissues with a high metabolic activity had a high turn-over rate of phosphorus because of increased nucleic acid metabolism. In polycythemia vera there is a greatly increased activity of the crythropoietic elements of the bone-marrow (red blood-cell forming tissues) and when phosphorus 32 is administered the isotope soon is concentrated in and irradiating the very tissue involved in the disease process. Several hundred patients have been treated since 1939. In one series of patients the average length of remissions from the disease was about 33 months, in marked contrast to the shorter remissions obtained with conventional nonradioactive therapy.

Radiophosphorus also has been used to treat chronic leukemia with beneficial results in many cases. Good therapeutic results also have been achieved with phosphorus 32 treatment in some cases of giant follicle lymphoblastoma, multiple myeloma and lymphesarcoma—all tumor-forming or cancerous diseases.

Although the distribution of radiation dosages from parenterally administered phosphorus 32 is not uniform, the entire body does receive appreciable amounts of radiation. For this reason, future applications of soluble phosphorus 32 compounds appear limited to the diseases described above.

Treatment With Colloids

Radiocolloids have become a useful tool in the palliative therapy of malignancies. There are three main pathways for the administration of these suspensions of solids in a fluid carrier—intravenous injection, direct injection or infiltration of the tumor and instillation in various body cavities.

The most common application at this time is the intracavity injection of radiogold colloids for the control of malignant liquid effusions. It is agreed that about half the patients with malignant effusions receive definite benefit in the form of increased comfort although there is no evidence of increased life expectancy.

The injection of radiocolloids directly into a tumor mass has been advocated by a number of workers. The technical difficulties in insuring anything approaching a uniform distribution in the tumor have prevented general acceptance of this technique except for tumors that are inoperable but not spread very widely.

Intravenous Injection and Clearance

The ability of an organ, such as the kidney or liver, to remove a specific substance from the blood and concentrate it as an excretory product, has not found practical application in therapy. However, the fact that certain compounds, such as Diodrast, can be concentrated by the kidney does provide an avenue for additional investigation in the future.

Intracavity Insertion

One method of using cobalt 60 in implantation therapy is in the form of small cobalt cylinders in needles similar to standard radium needles. However, it is difficult to make a choice between the two sources of radiation. The difference in cost is not a deciding factor.

Cobalt 60 is safer to use, but less experience is available on dosimetry, and the shorter half-life of radioactive cobalt, with more rapid loss of effective radiation, is a definite disadvantage.

Cobalt needles of special configurations have been used to treat neoplasms such as carcinoma of the cervix, but no great increase in the use of cobalt 60 for intracavity implantation is anticipated.

Various radioisotopes are being used in cases of bladder cancer which cannot be treated by surgery. A solution or suspension of a radioisotope such as sodium 24, bromine 82 or cobalt 60 is introduced into the bladder within a balloon.

Interstitial Implantation

Two advantages of cobalt 60 and other radioisotopes over radium are the smaller size of the source required to give a certain dose of radiation, and the greater ease and safety in handling the isotope. Use of a cobalt and nickel or chromium alloy encapsulated in gold or silver or plated with nickel or chromium is much less likely to result in accidental contamination. Small cobalt 60 needles may be place at intervals in plastic tubing or ribbon. The plastic is flexible and the radioactive pieces are held safely in place with little or no discomfort to the patient.

Gold 198 has found considerable application in the form of seeds, comparable to the older radon seeds. The half-lives of the two radioelements are similar. Gold 198 seeds are somewhat easier to prepare and handle than radon seeds, and at the prsent time are more readily available to the average hospital. Again, the extensive clinical experience with radon seeds has created a large body of empirical information that is lacking with respect to gold 198. However, the greater availability of radiogold should see a continuing increase in its use.

A recent contribution of a radioisotope to the palliative treatment of cancer is the use of yttrium 90 to destroy the pituitary gland. This gland is located adjacent to the base of the brain. Although it has been known for many years that destruction of this gland results in dramatic temporary relief to many cancer patients, the removal of the gland by surgery was a difficult and dangerous procedure. A technique devised at the Argonne Cancer Research Hospital has resulted in the successful eradication of the gland by implanting pellets of beta emitting yttrium 90. The procedure is much less dangerous than surgery and the results are, in general, encouraging.

Topical Applications

The first artificially produced isotope to be used therapeutically, phosphorus 32, was investigated as a topical agent at an early date. Blotting paper, and later plastic, impregnated with the isotope have been used to treat a variety of surface lesions. A high dose can be delivered to the superficial layer with almost no radiation delivered to the underlying tissue. However, the short half-life of phosphorus 32 is a decided disadvantage, as new applicators must be processed for each treatment. The technique does have decided advantages over the use of soft X-rays in treating certain shallow widespread lesions.

Ophthalmic Applicators

Perhaps the greatest use of beta ray applicators is in the treatment of diseases of the eye, particularly the cornea and epibulbar regions. As a result of the limited penetration of the beta radiation, little if

any radiation is delivered to the interior of the structures. The radioisotope can be fabricated in shapes that permit intimate contact with the diseased area.

Perhaps the most useful isotope for this purpose is strontium 90. It has a relatively long half-life (about 26 years) and can deliver adequate dose rates. The use of ophthalmic applicators does not appear to be increasing rapidly, as other equally useful sources of radiation are usually available to the radiation therapist.

Teletherapy

It was first proposed in 1948 that cobalt 60 be used in a supervoltage teletherapy unit for treatment of malignancies and similar purposes. The original idea envisioned a simple substitution of cobalt 60 in a radium-pack type of machine. After adoption of this idea, a 10 curie cobalt source was rapidly changed to 100 and subsequently to 1,000 or more curies.

At that time very little was known of the physical characteristics of cobalt 60 radiation. A comprehensive study in this area was undertaken by the Medical Division of the Oak Ridge Institute of Nuclear Studies. The first teletherapy unit was designed in 1950 and built by General Electric. By 1951, both the source and the complete unit were available and isodose curves were plotted from this first source.

Since then, more than 200 individual sources were produced in the United States and cobalt 60 has assumed an important role in the radiotherapy departments of many leading hospitals and medical centers throughout the country.

One major problem associated with cobalt teletherapy is room shielding. Since a substantial portion of the costs for purchasing a cobalt unit involved shielding, employment of an isotope other than cobalt 60 was considered—one with an energy emission requiring less costly shielding. One obvious choice was cesium 137, but cesium 137 was not readily available.

The first available cesium source was placed in the ORINS unit in 1953 and its physical characteristics carefully studied. The Commission placed a second source (2,000 curies) in the radiation therapy center at the University of Michigan for clinical evaluation. Results to date indicate that cesium offers an advantage over cobalt only with respect to its longer half-life and the decreased shielding requirements. Nevertheless, cesium radiation can be useful in clinical radiotherapy, especially for the treatment of superficial lesions.

Teletherapy has been a worldwide development, and progress within the past few years has been significant. In the United States several different lines of development have taken place, as for example, the development of a floor-stand model to contain either a kilocurie or a hectocurie source—the latter used in smaller hospitals—and a rotational unit of kilocurie size.

Many other countries have also developed teletherapy programs; in particular, the Canadian market offers a large source teletherapy unit large and small rotating units, and a hectocurie floor-stand unit.

Use of Accelerators and Reactors

Reactors.—Though the applications of accelerators to medicine were initiated some 25 years ago with the advent of radioactive isotopes, the first nuclear reactor designed specifically for medical use was com-

pleted only recently. On December 17, 1958, the Medical Reactor at Brookhaven National Laboratory was dedicated, and on March 15, 1959, the reactor went critical. This new device will provide a neutron beam for the treatment of brain tumor patients.

Neutron capture therapy is a procedure which seeks to utilize the energy released by prompt decay of radioisotopes created in the tumor or lesion. Nonradioactive elements are introduced into the body and become localized in the tumor. A beam of neutrons directed at the tumor caused the nonradioactive elements to become radioactive. The prompt decay of these radioisotopes results in heavy ionization and destruction of tumor cells. Only three elements are available with a large thermal neutron capture cross section and with the property of rapid disintegration into energetic particles. Of the three elements, lithium 6, uranium 235, and boron 10, the last has been employed in studies with brain tumor patients. Boron 10, following neutron capture, disintegrates into an alpha particle and a lithium particle with an energy release of 2.4 Mev. The application of this neutron therapy to patients has been limited to lesions associated with a brain cancer, usually glioblastoma multiforme.

In addition to Brookhaven, Massachusetts General Hospital is actively engaged in this problem and looks forward to patient treatment through the medical port of a new reactor at Massachusetts Institute of Technology.

Accelerators.—The use of electron or positive ion accelerators in biomedical research is very widespread today. Most current efforts in the United States are directed toward fundamental understanding of the nature of biological effects of various radiations and also to study various disease problems including patient therapy. The types of accelerators available include the Van de Graaff generator (for electrons or positive particles), electron linear accelerators, betatrons, synchrotrons, cyclotrons, synchrocylotrons, and heavy particle linear accelerators.

The chief advantage of high-energy X-ray beams in radiology is in the depth dose penetration curve. The depth of penetration is proportional to beam energy and can be controlled; the exit dose is low and large skin areas can be irradiated with relatively uniform depth irradiation.

High-energy X-rays and ions are currently employed in therapeutic investigations on known, deep-seated, localizable tumors, and metastases of a localized character. This approach is followed with the Atomic Energy Commission supported 70 Mev Synchrotron at the University of California School of Medicine in San Francisco where patient treatment has been continuing for some time. At the Argonne Cancer Research Hospital, a recently completed 50 Mev linear accelerator has been fitted with an electron beam scanner which will automatically cover a predetermined skin area of irregular contours, with particles penetrating to any desired depth up to the full range of their electrons.

Radiation hypophysectomy (destruction of the pituitary gland) has aroused interest among medical researchers, particularly since hypophysectiomized rats were shown to have a lowered tumor incidence. Some 5 years ago, radiation hypophysectomy was attempted with 340 Mev protons on patients with advanced metastatic carcinoma of the breast. Since this early experiment, many patients have been treated in this manner at the Berkeley cyclotron. Signs resembling complete hypophysectomy appear within 3 months. The results have proved beneficial in nearly 50 percent of the cases treated.

LETTER REQUEST TO PUBLIC HEALTH SERVICE

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Accordingly, it would be deeply appreciated if the United States Public Health Service could prepare a brief letter report of its programs in the peaceful uses of atomic energy.

Reports of this nature have been furnished by the Atomic Energy Commission, which has suggested that your department be contacted for information concerning programs which are not operated under the principal direction of the AEC.

The background reports contained in Volume II of the Report of the Panel on the Peaceful Uses of Atomic Energy provide a useful guideline for the information being sought in connection with the present study.

TRANSMITTAL LETTER FROM PUBLIC HEALTH SERVICE

I appreciate very much the opportunity you have given the Public Health Service to present, by means of this letter, a brief report of our programs in the peaceful uses of atomic energy.

At the outset I am happy to state that since the 1956 hearings on this same subject substantial progress has been made by the Public Health Service in its programs that represent or affect peaceful uses of atomic energy. Generally speaking these programs have been in two broad areas: (a) Research which employs the by-products of the nation's atomic energy program; and (b) Establishing the degree of radiation protection for the general public that is prerequisite to full development of atomic energy and constructive use of its by-products. I am attaching a brief summary of these two areas of our work.

There are many other important developments that deserve mentioning. However, this summary should indicate the scope and direction of our efforts to acquire knowledge and erect safeguards that will permit full utilization of ionizing radiation for the benefit of society.

Department of Health, Education, and Welfare

Public Health Service

SUMMARY

Peaceful Uses of Atomic Energy in Public Health Programs

RESEARCH: Among the major responsibilities of the Public Health Service is the conduct and sponsorship of basic medical and biological research. The objective is to increase our knowledge of health and disease in general, and to discover new or improved methods for diagnosing, treating or preventing human illness.

In the last decade great and rapidly increasing contributions have been made by U.S. scientists to the advancement of world-wide medical knowledge. Much of this work is financed by federal funds that have been made available by the Congress for research by the National Institutes of Health, research arm of the Public Health Service, and for research grants to non-federal scientists. A significantly related factor is the availability of new research methods and tools, of which radioactive isotopes derived from atomic energy processes are among the most important. While exact figures are not immediately available, a safe estimate would be

that as much as 50% of all fundamental medical and related biological research today depends to a greater or lesser degree upon the use of such isotopes.

The importance of radioactive isotopes to modern medical research is plain. There is good reason to believe that many of the diseases and impairments of man are due to obscure molecular disturbances within the various tissues and organs of the body. By attaching radioactive atoms to specific molecules it is now possible to study these disturbances in a fashion previously impossible. The technique of tracer studies and the plentiful availability of man-made radioactive replicas of many of the elements involved in normal body processes provides a research tool of very great importance. Not only does this product of peaceful atomic energy hold great promise for solving many specific health problems but it has provided vital impetus to studies of basic mechanisms of the life process which will greatly increase our knowledge of all biological phenomena.

A few examples of recent advances in medical knowledge primarily attributable to this new tool will illustrate my point.

Examples of Research Employing
Isotopes or Radioactive Tracer Chemicals

The following are examples of recent advances in medical-biological knowledge and health procedures primarily attributable to the use of radionuclides as a research tool.

A new test for possible loss of blood plasma proteins from the gastrointestinal tract, using polyvinylpyrrolidone made radioactive with Iodine-131, showed that contrary to previous theory, cholera patients do not lose appreciable quantities of protein; that protein replacement is therefore not a necessary part of treatment of cholera; and that there is no extensive destruction of the intestinal lining in cholera. These findings were made by Dr. Robert S. Gordon, Jr., of the National Heart Institute, National Institutes of Health, on cholera patients in Bangkok during the recent epidemic there. The test, devised by Dr. Gordon, is also proving useful in studies of other conditions in which protein loss via the gastrointestinal tract is a problem.

Also at the National Heart Institute, scientists have used radioactive gas (krypton^{85}) to detect and locate accurately certain heart defects, thus making corrective surgery possible, and to detect, more simply than heretofore possible, abnormal channels in the portal vein system of the liver, thus facilitating surgical treatment. (Drs. Robert T. L. Long, Carlow R. Lombardo, Eugene Braunwald, Andrew G. Morrow, on the portal veins; and Dr. Richard Sanderson, on the heart septal defects.)

Using a radioisotope of rubidium (Rb^{86}), Dr. George C. Henegar, working under a Public Health Service research grant at Northwestern University Medical School and the VA Hospital, Chicago, developed a rapid and more completely informative method of determining the degree of potassium loss by the body, important because potassium depletion results in muscle weakness and can become life-threatening.

Cell development in the relatively inaccessible mammalian embryo can now be traced by autoradiography using tritium-labelled thymidine (thymidine-H^3) which becomes incorporated into a basic chemical component of cells preparing for division. This method was developed by Dr. Richard L. Sidman and associates of the National Institute of Neurological Diseases and Blindness, NIH.

Radioactive isotopes have been used in a new method developed by Duke University scientists for measuring absorption of materials from the colon into the blood stream. The method may prove of great value in the study of ulcerative colitis and other gastrointestinal diseases.

Radioactive isotopes have gained wide usage in many of the regular health protection and laboratory analysis activities of Federal, State and local health agencies. Indicative are the following examples of radiotracer techniques that are taught to students in the radiological health training courses given at our Sanitary Engineering Center in Cincinnati.

The use of phosphorus-32 in uptake, translocating and metabolism by plants. The radionuclide is localized in the plant by autoradiographic techniques.

Determination of bio-oxidation rate of organic waste by sewage slime through the incorporation of phosphorus-32 into the synthetic sewage.

Utilizing chromium-51 in hematological studies with rabbits which have received acute exposure doses of X-rays. Red blood cells are tagged with chromium-51 in vitro and then re-injected into the experimental animals to determine:

(a) Total blood volume by withdrawal of a small volume of blood after the tagged blood has been evenly dispersed.

(b) Half-time survival of tagged red blood cells which are damaged by the acute effects of X-rays on the circulating blood elements and the hematopoietic system.

Studying uptake of strontium-89 in the oysters. Percentage of isotope removed from brackish water and specific organ uptake activity are included.

Similarly, radionuclides are extensively used in original studies to develop new or improved environmental health procedures or obtain needed biological knowledge at Cincinnati. The following are typical examples:

Laboratory studies employing radioactive isotopes are under way to determine the uptake of calcium, strontium, cesium, potassium, and ruthenium by fishes, algae, snails, and other aquatic organisms and clayey minerals.

Extensive studies are being undertaken in the use of radionuclides in the development and calibration of instruments for accurate evaluation of environmental radioactivity levels and in the evaluation of analytical chemical procedures.

Rubidium-86 is being used on the evaluation of experimental pilot plant facilities for improved sewage treatment, and radioactive iodine (I^{131}) in studies of improved methods for pasteurizing milk. The principles of neutron activation have been applied to the determination of trace quantities of specific chemical pollutants in water and air and also for the determination of stable strontium in milk.

A prototype radioactivity analyzer for atmospheric pollution study has been developed, in which a beta technique utilizing carbon-14 is applied to measurement of the thickness of dust deposits collected on membrane tape. This instrument also measures the alpha and beta radioactivity content of the dust deposit. Concentrations of natural radioactivity by alpha detection can be measured as low as 35 picocuries per cubic meter and artificial radioactivity concentrations by beta detection at 18 picocuries per cubic meter, both values being well within recommended maximum permissible levels in air.

The U. S. Public Health Service hospitals have been experiencing beneficial results from the generally accepted methods of utilizing radioactive isotopes in clinical diagnosis, therapy and research. A few examples include:

I-131 in studies of thyroid function and in treating hyperthyroidism; Cobalt tagged vitamin B-12 in macrocytic anemias such as pernicious anemia; Phosphorus-32 in polycythemia vera; and Gold-198 in treating cancer that involves the inner lining of the lungs and abdomen.

A member of the staff of our hospital on Staten Island has presented a new method of diagnosing certain types of diseases of the arteries of the arms and legs, using radioactive iodine to evaluate rate of blood flow in the extremities. The immediate application is to determine which place should have further X-ray studies. It also can be used to determine progress or results of medical or surgical treatment of these conditions. It is anticipated that this method has wide application in the study of hardening of the arteries. Its use in the diagnosis of other vascular diseases appears promising.

RADIATION PROTECTION: The Public Health Service has been keenly interested in radiation protection since the early industrial usage of radium and the widespread application of X-rays in medicine and dentistry. With the advent of expanded peaceful use of nuclear power and the increased application of isotopes and X-rays to medicine and to industrial and agricultural processes, our radiation protection activities are being greatly expanded. These are focused in our Division of Radiological Health, but closely integrated with the related environmental health activities of the water pollution and air pollution programs--all of which are located in the Bureau of State Services of the Public Health Service.

The growth of our radiation protection program is reflected in the funds made available to the Division of Radiological Health by the Congress since the Division was created at the beginning of the 1959 fiscal year. For that year, $685,688 were available. This was increased to $2,844,900 in the current fiscal year, 1960. For fiscal year 1961 we have requested an increase to $6,219,000.

The classical pattern for nationwide public health work in this country on any newly emerging problem is for the Federal health service to assist State and local public health agencies to develop adequate programs close to the population groups affected. This pattern is being followed for radiological health activities, and consists of three principal components--training, technical assistance and research.

I am pleased to report very substantial progress in all three of these areas, in spite of the acute, nationwide shortage of qualified radiological health specialists.

Training: Because of that shortage a major part of our funds specifically set aside for radiological health is being devoted to training State, local and Federal personnel in the fundamentals of this work. In 1959 intensive short training courses were given at the Sanitary Engineering Center in Cincinnati to 386 persons; in 1960 this figure will be almost doubled; in 1961 we expect to train about 900. The majority of these trainees have been from State and city health agencies.

Advanced academic training is needed at a continuing rate of about 50 professional Public Health Service personnel annually. We are now operating at a level of 26, and next year expect to attain the desired level of 50 people in advanced training.

After careful study a committee of non-federal experts has advised me that by 1970 Federal, State and local public health programs will require at least 1,200 professional people with special graduate training in radiation health, capable of assuming a high order of responsibility in radiation control activities. In addition, the nation's future physicians, dentists and engineers should have better knowledge of this new, highly complex field. To achieve these ends we are encouraging colleges and universities to incorporate radiological health subjects into their curricula and to establish major radiological health courses.

In addition we are greatly increasing our programs for developing needed manuals and other training materials for use by these institutions and by State health agencies.

A related activity is our Analytical Reference Service conducted by the Sanitary Engineering Center at Cincinnati. This Service gives aid in laboratory methods to State, local and other health offices, including those in other Federal agencies, in universities, and in industry. The Analytical Reference Service, a volunteer association of member organizations responsible for the conduct of laboratory programs in radiological health, provides on the job training in the improvement and evaluation of laboratory procedures. Participants compare their procedures and results with those of other laboratories having similar responsibilities, exchange technical information and evaluate new methods. At present, efforts are being directed toward the chemical examination of water for radionuclides, but the scope will be broadened to include other media and other types of examinations. At present, participants include 41 health organizations in 35 States, four municipal agencies, 10 installations of four different Federal agencies, five universities, and two Canadian health departments.

Technical assistance: One objective of our technical assistance program is to place a radiological health specialist in each of our Regional Offices for consultation with the States. Four have been assigned thus far and within the next several months we expect to have one or more consultants in all 8 Regional Offices. In addition, 13 Federal specialists have been

assigned directly to as many State agencies, and many more will be similarly assigned when they become available. An inventory of 40 State programs shows that all have begun radiation protection activities and that several have made very good progress in this important new field. Our technical assistance program is designed to speed up this process.

An important phase of technical assistance which often transcends State boundaries is the direct assignment of qualified federal personnel to special projects of other federal agencies. In addition to providing radiological health competence to such projects these representatives of the Public Health Service usually serve as liaison between the projects and the State health agencies involved. Brief descriptions of three such special projects of current importance follow.

Shippingport Reactor Project: For the past five years we have had an officer working as part of the staff of the Pittsburgh Naval Reactors Operation Office at the Shippingport Pennsylvania Power Reactor Site. A primary purpose of this assignment was to provide a man on the staff at Pittsburgh who could work effectively with the health authorities of the States concerned with possible health problems arising from the construction and operation of the Shippingport Reactor. This officer has other responsibilities including those associated with waste treatment and disposal, environmental monitoring, emergency plans, etc. Experience gained through this assignment has significantly increased the Service's competence to consult with State health agencies interested in application of nuclear reactors for production of electrical power.

Nuclear Powered Merchant Ship Program: Current activities of Service personnel assigned to the Nuclear Powered Merchant Ship Program of the Atomic Energy Commission and the Maritime Administration are directed in three general areas.

(a) Engineering activities to evaluate the environmental hazards potential from any operating nuclear ship, including surrounding environments in which the vessel operates;

(b) Medical health physics to develop, implement, staff and review a medical care and radiation protection program for the crew, passengers and visitors and advise on medical implications from environmental hazards.

(c) The preoperational environmental survey of the Delaware River site of proposed initial operation of the N.S. Savannah with the cooperation of States and local government agencies.

This survey will establish the condition of the environment in terms of radioactivity, before, during and after the initial operation of the Savannah. It will check the design of the planned system for complete containment of radioactive wastes.

While these activities have pointed toward the N.S. Savannah, our primary interest remains in providing assistance to all areas of the nuclear ship program; tanker, advanced reactor systems, training, international studies and liaison with other federal agencies concerned with maritime reactors including the Coast Guard, AEC, and Maritime Administration.

National Reactor Testing Station: Since 1956 PHS has had an engineer officer assigned to the Health and Safety Division, National Reactor Testing Station, Idaho Operations Office, of the Atomic Energy Commission.

In 1958 we agreed to staff a Monitoring Evaluation Project to be conducted at NRTS. The broad objective of this study is to develop information on practical environmental monitoring and surveillance programs to be used by industry and by regulatory agencies to determine and evaluate possible radioactive contamination resulting from the several types of reactors and related industrial processes. The staff of five officers assigned to the project now concentrate their efforts on establishing parameters for sampling and monitoring, development of monitoring and sampling equipment, and correlating meteorological predictions with field results.

Research: In addition to the basic research activities at NIH, we are conducting a rapidly growing research program of epidemiological investigations, environmental surveillance and data analysis. The primary purpose of these activities is to obtain meaningful nationwide data on the location, kinds and amounts of chronic, low-level environmental radiation and their effects on the population groups involved.

Two regional laboratories were established during the current year to assist the States in the laboratory analysis phase of radiation surveillance, and in laboratory training work. They are the forerunners of similar laboratories which will be located at strategic points throughout the country. A third laboratory especially designed for investigating problems of medical and dental X-rays and for special training in this field is under construction.

The nationwide milk sampling network is being expanded from the present 12 to about 60 stations.

The radiation surveillance network of 44 stations which collect samples of air and rainfall for analysis, and measure background radiation, will be expanded next year.

The data being obtained through these networks is being supplemented by and correlated with a greatly expanded program for intensive epidemiological and nutritional research in selected population groups. This work which is just getting under way, will involve very close collaboration between the Federal, State and local public health programs and cooperating universities. There is excellent coordination with other Federal research and regulatory efforts, including those of the Food and Drug Administration and the Atomic Energy Commission.

Similarly, nationally and within the States there have been many examples of collaboration with physicians, dentists and their professional organizations. An example is the cooperative program with the American College of Radiology for financing nationwide distribution of their excellent film which instructs physicians in methods for reducing unnecessary X-ray exposure to patients and operators. Many local medical and dental societies have given active support to programs of professional education, and for registration and calibration of X-ray equipment.

In this same vein, local medical societies, medical schools, and individual physicians have worked closely with health agencies on epidemiological studies, have provided pathological specimens for radiological analysis, and have rendered many other professional and advisory services in connection with radiation protection and research activities.

More comprehensive data on radiation exposure sources and levels and radiation dose levels and body burdens are necessities to nearly every aspect of the radiological health program. Various existing data collection networks have produced parts of the total needed data. It is now essential that a more integrated approach be taken by these existing data collection activities and that this work be extended to include presently untouched areas.

This goal will be realized through the development of an expanded Radiation Intelligence Network by the Division. Through this mechanism, it will be possible to pinpoint problem areas or population groups in which to conduct epidemiological studies.

At present, we have no firm knowledge of what total exposure and doses are being experienced by various important segments of the population or how these compare to currently advocated standards. The need for this information is critical, as is evidenced by the recent recommendation of an ad hoc committee of the National Committee on Radiation Protection and Measurements that exposure of the general population from man-made sources of radiation, exclusive of medical exposures, should not exceed that resulting from natural background.

Through this program of comprehensive intelligence, it will be possible to study the mechanism and links involved in exposures to the population and thus to pinpoint research efforts and control techniques that are designed to interrupt these mechanisms and break the links at their most vulnerable points.

Data Collation and Analysis: In August 1959, the President directed the Secretary of Health, Education, and Welfare to intensify Departmental activities in the field of radiological health. The Department was assigned, among other things, primary responsibility within the Executive Branch for the collation, analysis, and interpretation of data on environmental radiation levels. Within the Department this responsibility has been delegated to our Division of Radiological Health.

As a step in the discharge of this responsibility, a monthly publication has been initiated. The data are submitted by agencies of the Federal Government, by States, and by other sources. Each third report, starting July 1960 will contain interpretative statements as well as data.

The monthly and quarterly reports are reviewed by a Board of Editorial Advisors with representatives from the following Federal agencies: Department of Health, Education, and Welfare; Atomic Energy Commission; Department of Defense; Department of Commerce; Department of Agriculture.

By 1962, it is anticipated that the staff will be sufficiently experienced and the data collection for these reports sufficiently standardized, that the next phase can be started. This next step will consist of carrying out analysis and interpretation of this data in depth. To accomplish this, a small staff of technical personnel will be recruited from different professional competencies such as mathematics, biology and physics.

Public Information and Education: Unreasoning fear of the hazards of radiation seems to be the dominant public attitude. In apparent contradiction, one often encounters a strange kind of fatalism or indifference

to these same hazards. The common denominator is lack of accurate knowledge due largely to the extraordinary complexity of ionizing radiation, its newness, and its difficult terminology.

From long experience, health officials know the importance of achieving widespread public understanding of any important national, regional or local health problem. Without that understanding preventive or corrective measures often are difficult, sometimes impossible.

In an attempt to achieve as quickly as possible public awareness of the nature of radioactivity, its sources, benefits, hazards and necessary protective measures, we are recruiting a staff of experienced technical and public information workers to conduct a nationwide educational program for the general public and for groups having special concern with various aspects of radiation.

For the general public we have increased our efforts to interest newspapers, magazines, TV stations and other communications media in the subject.

For special groups such as physicians, dentists and scientists we are already working closely with their national organizations on programs designed to convey the pertinent facts to their State and local groups.

Many of these activities are being developed and will be carried out in close cooperation with the health education, informational and technical staffs of State and local health departments. For both national and local use, a variety of educational and informational materials are being developed, including motion pictures, pamphlets and exhibits.

Paralleling these activities is a planned program for appropriate approaches to labor and management groups, industry, fraternal and civic organizations.

Implicit to our whole approach is the philosophy that the public not only needs to know but has the right to know all the facts about a subject which has a potential for benefit as well as harm for every individual in the United States.

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

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With this letter I am enclosing in response to your request two papers prepared by the Office of Isotopes Development.

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RADIOISOTOPES IN SCIENCE AND INDUSTRY

SUMMARY

THE IMPACT of radioisotopes and radiation applications on science and industry is an important chapter in the Nation's scientific and technological progress. This special report of the Atomic Energy Commission reviews briefly the contributions of radioisotopes to the sciences, agriculture, medicine, and industry, and summarizes Commission programs designed to broaden the use of radioisotopes, and to increase their assistance to the national welfare and economy.

Many of the applications presently in use have been built upon initial work done in Commission laboratories, and under Commission contracts, and made available for public and private use; private research institutions and industry have been responsible for other accomplishments reported. The Commission's current, newly expanded programs are designed to solve impeding research and technological problems and in this way increase the contributions of radioisotopes. The results of all Commission work and contracts in this field are being published as promptly as available, and freely offered for the use of all elements of the economy. Training courses also are being presented to increase the number of persons able to use isotopes safely and effectively.

Separate chapters of this report deal with: the progress of research in agricultural and other biological fields; the applications of radioisotopes and radiation to medical diagnosis and therapy; the benefits of isotopes in chemical and physical research; examples of existing industrial uses; some problems of industrial development and studies aimed at solving them for broad segments of the economy; the potential of high intensity radiation in industrial processes; the training program that assists broader uses of radioisotopes; trends in isotope production, distribution, and pricing; and the Commission's methods and enforcement to safeguard health and safety in the use of radioisotopes and radiation.

BEGINNING OF THE ISOTOPES PROGRAM

The existence of isotopes apparently first was discovered about 1907 after nearly a decade of experiment with naturally radioactive materials and their emanations. The discovery was that two samples of material which had differing radioactivity apparently were chemically identical. It was later that these differing physical forms of atoms which were chemically identical were christened isotopes -- indicating that they fell in the same (iso) place (topos) in the periodical table of chemical elements.

By 1934, scientists had learned that, by use of such newly invented "atommashers" as cyclotrons, radioactivity could be induced in normally stable chemical elements. With this discovery, it became widely recognized that man-produced radioactive isotopes would be powerful new tools of research and development, and versatile sources of radiation.

In the first decade after the discovery of man-made radioactivity, radioisotopes were manufactured on a limited scale in cyclotrons and other costly particle accelerators, and were applied to many research problems. With the advent in the 1940's of the nuclear reactor, producing quantities of radioactive atoms, the door opened to the greater realization of the promise of radioisotopes.

The first formal discussion on distribution of radioisotopes produced in nuclear reactors was held in 1945 in Washington by members of the National Research Council Committee on Growth, and the first public announcement that reactor radioisotopes were available from the Army Corps of Engineers Manhattan District, war-time operations of the United States atomic energy programs was published in the June 14, 1946, issue of Science. The first shipment, a small unit of carbon 14, was made to the Barnard Cancer Hospital in St. Louis, Mo., on August 2, 1946. This marked the beginning of the Nation's effort to develop the peaceful uses of atomic energy.

In less than 6 months following the start of the distribution program, the Atomic Energy Commission, under the authority of the Atomic Energy Act of 1946, took over administration of the atomic energy project. The Act was instrumental in providing for the distribution of radioisotopes.

Oak Ridge National Laboratory, originally the Clinton Laboratories, developed as the primary supplier of radioisotopes. Later, other Commission laboratories began producing radioisotopes to meet various specific needs as they arose. In addition to Oak Ridge, radioisotopes were being produced in 1959 at Brookhaven National Laboratory, Argonne National Laboratory, the National Reactor Testing Station, the Savannah River Plant, Hanford Works, and Mound Laboratory. Oak Ridge National Laboratory has remained the main center for distribution.

Since these beginnings, private research institutions, universities, hospitals, and industry as well as federally financed installations, have carried forward research and practical usages of radioisotopes on a broad scale.

The Commission has followed a steady policy of supporting private enterprise activities in supplying radioisotope materials and services, and developing new uses. Many of the services previously supplied by the Commission, such as source encapsulation, instrument design and production, and standardization, and retail distribution of radioisotope compounds, have been taken over and expanded by private organizations as they reached profitable proportions. The Commission's radioisotope production laboratories now function largely as bulk suppliers.

STATUS OF ISOTOPES USE -- 1959

As of December 31, 1959, the Commission had licensed 2,286 institutions to use radioisotopes in medical diagnostic and therapeutic applications;

1,623 companies to use radioisotopes in addition to the many cases in which radioisotopic tools can be used under general licenses; and 1,596 groups to use them in research and development work of various kinds. The total ~~estimated~~ licenses at year end represented a 26 per cent increase over the total for 1958 and 62 per cent over 1957.

Shipments of radioisotopes from Commission laboratories increased steadily through the years both in number and total quantities shipped. Figures from Oak Ridge National Laboratory show a rise from 14,126 shipments of a total of 166,629 curies in the year 1957 to 14,131 shipments of 228,714 curies in the next year, and 12,950 shipments of a total of 299,365 curies in 1959 ~~[illegible]~~. The shipments do not include those of retail suppliers which approximate 100,000 shipments per year.

Agricultural Uses

In agriculture, radioisotopes are an important tool that is helping scientists to unlock secrets of the growth of plants and animals and the pests and diseases that injure or destroy them. They are contributing to increasing productivity and better economy. They have been applied in a variety of research on plant nutrition, crop diseases, fertilizer application and effectiveness, soil conditions, animal diseases, milk production, insect eradication, and development of new plant varieties through mutations. Over $5 million per year of agricultural research is performed with radioisotopes.

Agricultural research often requires years to mature because of crop cycles, and additional time which elapses before results can be applied on the farms. Except in a few instances, the agricultural benefits of isotopes lie chiefly in the future.

Medical Uses

Following the discovery of radium in 1898, medical researchers soon recognized the possibilities of using radioactivity.

The supremacy of radioactive elements as tracers to define physiological processes is readily apparent in medical and biological fields. The tracers correspond in size and kind to the thing they trace. They are not foreign or chemically different -- they are the material or a true part thereof. Some disease processes that have been studied are cancer, leukemia, heart malfunctions, arteriosclerosis, virus infections, multiple sclerosis, arthritis, anemia, gout, and nutritional deficiencies.

In addition to such universal use of tracers for biomedical research, radioisotopes have made possible some advances in medical diagnosis. Dynamic tracer diagnostic tests of the functions of organs in patients have been developed for thyroid, heart, liver, kidney, bone marrow, and spleen. Tracer tests are used routinely for the total volume of plasma,

blood or water in the body, for lifetime of blood cells, and for localization of tumors, particularly of the brain. Over 2,000 hospitals or medical groups use isotopes for diagnosis.

In the area of radiation treatment, radioisotopes found early applications in medicine. Many of the therapeutic uses, particularly in cancer treatment, follow the principles established with X-rays and radium. Radioisotopes have greatly extended these treatments. At end of 1959 over 300 radioisotope teletherapy units were licensed for use in the United States alone. These units may contain as much as several thousand curies of either Cobalt 60 or Cesium 137 radioisotopes.

Industrial Uses

Most of the widespread applications of radioisotopes that industry has developed use very little radiation and fall into two categories: radioisotopes for tracing, and small radiation source for gaging or testing.

Radiotracing applications, now in use include: wear and lubrication tests to find best lubricants and conditions of operation, involving piston rings, gears, and machine parts; wear tests on paints, varnishes, wax coatings, and other protective agents; study of detergents and various cleaning agents on cloth and fabrics; finding leaks inside complicated systems and underground gas storage depots; tracing flow in pipelines, streams and underground gas storage depots; tracing flow in pipelines, streams, catalytic crackers, chemical processing plants, and fluid or slurry systems.

In the area of radioinspection, industry has rapidly expanded radioisotope radiography as an efficient and cost-saving way of meeting the higher quality and greater safety specifications required for many products today -- both for civilian and military use. Welds are routinely radiographed with radioisotope "cameras" on ships, tanks, pipelines,and containment vessels. Such "radioeyes" also are used to tell whether the fuel in rockets meets the rigid requirements of uniformity so necessary for successful operation. Construction of a single ship often requires the radiographing of as many as 10,000 welds. The savings in rejects and elimination of destructive tests for welds, casts, and other fabricated products, is significant. Even more important is the greatly reduced chance of failures and accidents. Another important factor is radiation beam inspection of rapidly moving packages, cans, sheet material metal strip, and fluid products. Isotope gages have been developed to penetrate through or reflect from material to measure levels, content, thickness, or density of a number of kinds of products.

A broad scope of products now is controlled and improved by isotope gages. Since they permit products to be made much more uniform and of higher quality, the user or consumer benefits directly as well as indirectly through the assistance isotopes can give to improved efficiency and productivity to wide segments of the economy.

High intensity radiation is starting to receive its first routine uses, but its full development depends on considerable research. The intense radiation from large quantities of fission products may ultimately find use as a new industrial process reagent and create new products. Some types of grafted plastics, such as selective ion exchange membranes used in desalting sea water, can best be produced by irradiation.

Development of Radiation Instruments

Since the human senses cannot detect nuclear radiations except at extremely high levels, the development of systems of detection and measurement of radiation has been essential to development of the practical applications of radioisotopes. The design and manufacture of such instruments was the first branch of the private atomic energy industry established. Many instruments originally were designed and manufactured in the Government's atomic laboratories, but immediately after the war the Commission supported development of commercial manufacture. Significant advances have been made by industry in the development of more stable and sensitive circuits for radioisotope measuring applications. By 1959 about 120 companies were manufacturing a variety of instruments, detectors, special components, and accessories.

Nuclear radiation detectors developed to date may be classified according to several types.

In pulse systems, the output of the detector consists of a series of signals, each of which represents the interaction of a nuclear particle or gamma ray with the detector. The well-known Geiger counter is an example of a pulse detector. Another is the proportional counter which is able to identify different radioisotopes according to their characteristic radiations. Still another example is the scintillation counter which operates on the principle that when ionizing particles pass through certain crystals, liquids, or organic polymers, flashes of light (scintillations) are emitted. An electron multiplier phototube picks up the faint scintillations and amplifies the resulting pulses to be detected and identified by the measuring apparatus.

In non-pulse detection systems, the output is the average of the cumulative effects due to many interactions of radiation with the detector; no attempt is made to resolve the individual events. The current-producing ionization chamber is a good example; the output is proportional to the total ionization current produced within the detector. Another example is the photographic system. When a piece of film is exposed to radiation, the emulsion reacts in the same way as when struck by visible light. The amount of radiation can be estimated from darkening of the film. Colorimetric detection is another example. When radiation reacts with certain chemicals containing chlorine (i.e., trichlorethylene and water, or chloroform and water), hydrochloric acid is formed. This causes a change in color of certain dyes, and the degree of color change produced is dependent upon the amount of radiation received.

Several other detector systems have been used for specialized problems. These include cloud chambers for laboratory studies, nuclear-track photographic emulsion plates, crystal conducting counters, chemical detectors, and colorimetric devices for detection of large doses of radiation. In addition, a number of systems have been designed to detect and measure neutrons. Most of these have used boron, lithium or cadmium, in conjunction with one of the detector types discussed (except colorimetrics), to detect the secondary radiation resulting from neutron capture by these materials.

In the field of low level counting, university work on radiocarbon dating of archeological materials was important in early developments. Noteworthy in this field was the pioneering research on the screen wall counter by W. F. Libby at the Universities of California and Chicago. Libby's technique involved placement of the sample inside a counter that operated on the sensitive and simple Geiger principle.

In more recent years, some investigators have substituted acetylene gas synthesized from radiocarbon samples used in proportional counters for the screen wall counter. Other techniques are based on a variety of liquid scintillators that respond well to soft beta radiation when the sample is mixed with the liquid scintillators.

These developments in low-level counting are pointing a way for applying these techniques to industrial processing. Present-day instrumentation is suitable only for laboratory needs, and designs must be modified to meet the rigid requirements of industrial applications. Efforts toward development for low-level tracers in industrial processes are described in Chapter VII.

ISOTOPES DEVELOPMENT PROGRAM

Developments to date in applying radioisotopes and radiation to increasing human well being and to economic gains through progress in industry represent only the beginnings of what can be accomplished. The contribution of this new tool to scientific work is broad and continuous, and the Commission through its research programs regularly supports agricultural, biological, medical, physical and chemical projects employing radioisotopes and radiation both through its national laboratories and through research contracts. The increasing potential for putting radioisotopes and radiation to work in industry for the public benefit has led to inauguration of a program to supplement private effort, and to accelerate achievement in this field. In May 1957, the Atomic Energy Commission accordingly laid the groundwork for an isotopes development program. In February 1958, the Commission authorized a $5 million budget for isotopes development activities, and in December of that year established the Office of Isotopes Development to carry out the program.

The Isotopes Development Program has the general purpose of attacking basic problems which are retarding more widespread use of radioisotopes and radiation. The program, in its early stages, is emphasizing short-term,

exploratory development which demonstrates principles of application having broad interest and susceptible of extension to many elements of everyday life -- applied agriculture, medicine, and industry. Full benefits from the new developments will be won only as private effort carries out the necessary engineering and other utilization studies required to extend the new technology into practical uses. On completion, results of all developmental work done under Commission sponsorship will be published promptly for use by all interested elements of the economy.

First, there is a need for fundamental techniques development -- studies to evolve more new fundamental methods, to determine reaction mechanics, and to devise new radiation measuring methods. Examples of this type of development involve neutron capture processes, prompt as well as decay radiations, positron annihilation processes, coincidence techniques, neutron scattering processes, etc., in addition to the better known procedures for using alpha, beta and gamma radiation. In the development of radiometric methods of analysis of nonradioactive components, the reactions must be analyzed and taken through technique development to determine such things as proper chemical forms for the radioactive elements, efficiency of conversion, and reaction rates.

Second, the industrial process radiation program is being directed toward developing the field of applied radiation in the United States.

The growth of the nuclear power industry is providing an accumulation of fission products that can be a valuable byproduct instead of an increasing storage problem. Useful applications of process high-intensity radiation now are only in the exploratory stages. Eventually, use of radiation energy is expected to have national economic significance. To capitalize on the huge reservoir of radiation available from fission byproducts, the Commission has undertaken a series of contracts to survey potential uses of radiation in industry, and to study the technology and methods for efficient utilization in industrial processes.

Third, training in isotope technology is required to increase the numbers of research and industrial personnel acquainted with the technology of practical applications of isotopes and radiation. The Commission's training program includes (a) development and establishment of courses to provide training in the characteristics of radioisotopes, their safe use, and general applications; (b) provision for intensive courses on particular areas of use; and, for industry, (c) seminars and symposia designed to increase management and professional knowledge of the contribution of radioisotopes.

Fourth, the Commission's production activities are being directed toward making available commercial quantities of isotopes at economic prices -- yet making it attractive for private enterprise to undertake producing the greater volumes of special radioisotopes that will be required for full-scale exploitation of this new tool.

Authorized contract projects. In addition to the work done at its national laboratories, amounting to about $1 million during the fiscal year that ended June 30, 1959, and numerous contracts covering research in the agricultural, medical, and other scientific fields, the Commission undertook during that fiscal year a program of 93 contract and grant projects totaling $3.76 million for work looking toward wider industrial applications of radioisotopes and radiation. These contracts and grants are listed in Appendix 3. Individual categories are: Isotopes Applications, 37 contract projects totaling $2.1 million; High Intensity Radiation, 13 contract projects for $600,000; Education and Training, 7 contract projects for $170,000; Equipment Training Grants, 33 schools for $600,000; and Production and Process Development, 3 contract projects for $200,000.

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

* * * Following receipt of my letters * * * with which were enclosed reports prepared by several Divisions of the Atomic Energy Commission, you requested a report on isotopic power.

With this letter I enclose * * * a report on Isotopic Power prepared by the Office of Isotopes Development and also * * * a report on this subject prepared by the Martin Company for use by the Office of Isotopes Development.

ISOTOPIC POWER

By the U.S. Atomic Energy Commission

Radioisotopes can be used as the primary source of energy to produce electrical power at useful voltages and currents. For many applications which require 1 to 500 electrical watts for long periods of times, isotopic power provides a unique source of energy. Investigations have proved that safe, rugged, and reliable direct conversion power supplies can be built.

The fundamental principle underlying isotopic power is simple. Heat is generated when particulate or electromagnetic radiations emitted by encapsulated radioisotopes are absorbed in the containment material. A portion of this heat is converted to electricity by a suitable energy conversion technique, the remainder is dissipated to the external environment. Three basic schemes of conversion include turboelectric, thermoelectric, and thermionic techniques. Today, the thermoelectric system is the most advanced and offers immediate use. Thermocouples represent the most familiar application of this principle. When two dissimilar metals form a closed loop and the ends are at different temperatures, an electric current flows. Using radioisotope heat to produce the hot junction of a series of thermocouples, electricity is generated.

Radioisotopes considered for power generation include the fission products strontium 90, cesium 137, promethium 147, as well as plutonium 238, curium 242, and polonium 210. The fission product strontium 90, a beta emitter with long half life, appears to be the most promising radioisotope source for land and sea applications. A ceramic heat element of strontium-titanate has been developed which is essentially insoluble in fresh and sea water, thus assuring safe containment of strontium 90.

Radioisotope fueled generators are eminently suited to supplying power for a whole gamut of remotely located devices such as radio beacons, fallout and five warning alarms, infrared forest fire detectors, sea lane markers, reef identification buoys, navigational buoys, telephone cable repeaters and sonobuoys.

Of particular interest is the development of a strontium 90 powered automatic weather station. This is expected to afford means for international cooperation in collection of weather data.

The automatic weather station is being designed to operate for a minimum of two years without attendance or maintenance. The 5-watt strontium 90 generator itself is capable of operating much longer—at least 10 years. Obtaining certain information of atmospheric conditions in polar regions, on the tops of inaccessible moun-

tains, and in unfrequented parts of the oceans is of importance to all nations. Representative sampling of the atmosphere over the entire earth is essential to future development of numerical methods of weather prediction for longer periods ahead.

In many cases the weather reports from remote regions are essential in the day-to-day predictions for transoceanic air commerce. Better estimates of moisture in the atmosphere available for precipitation as rain or snow over marginal arid regions of the globe are also needed. All meteorological services recognize that any adequate weather reporting network must include automatic stations designed to operate for long periods without attendance in remote oceanic and polar areas.

Not only does the radioisotope powered automatic weather station provide a new means of obtaining basic weather data under circumstances impossible in any other way but it also provides a real possibility of utilizing waste fission products for the benefit of mankind.

ISOTOPIC POWER

Prepared by the Martin Company for the Office of Isotopes Development, U.S. Atomic Energy Commission

INTRODUCTION

During the past five years a marked increase in technological requirements for small, dependable, and long-lived electrical power supplies for unattended use has led the Atomic Energy Commission to support an extensive program of research and development which is centered around the use of radioisotopes as the primary source of energy. Although the program was initiated specifically to provide a radioisotope power source for an earth reconnaissance satellite, a host of related and other applications has arisen as the research program makes strides in demonstrating the feasibility of isotopic power. Through the first half of Fiscal Year 1960, approximately $9 million had been invested by the AEC in the program.

The capabilities and limitations of isotopic power arise from both technical and economic considerations. The principal technical factors involved are the half-life of the isotope selected and the efficiency of the conversion devices available. Use can be made of long-lived isotopes of very moderate power-producing ability or the shorter lived isotopes can be used. With the shorter lived isotopes a penalty of either a short power supply life or more massive heat dissipation apparatus must be tolerated. The latter is required to reject a considerable amount of energy early in the life of the power supply if a constant power output is required. Thermoelectric, thermionic, and turboelectric conversion devices are all feasible for specific applications. The energy conversion system chosen is very heavily influenced by the end-use or mission requirements, frequently to such an extent that the conversion efficiency is overshadowed. The availability of suitable radioisotopes in very large quantities is presently, but temporarily, limited because there is no suitable separation facility in existence. The supply of feed material for such a facility is ample. The construction of a separations facility would make fission products available in large quantities and would also provide some

radioisotopes at less than one-tenth of today's prices. Mixed fission products are not usable as such because of low power densities, and separation and purification of specific isotopes from these products is required for power applications.

Finally, attention must be given to the design and development of the operational unit. Adequate shielding and reliable assurance of safety of use are mandatory.

PRINCIPLES OF CONVERSION OF THERMAL TO ELECTRICAL POWER

The fundamental principle underlying isotopic power is simple. Heat is generated when the particulate or electromagnetic radiations emitted by sealed radioistotopes are absorbed in the surrounding containment material. A portion of this heat is converted to electricity by a suitable energy conversion device, the rest is dissipated to the external environment.

The conversion of the heat produced by radionuclides into electricity is a problem which is independent of the radioisotope selected as fuel. Three basic schemes may be used: rotating machinery (turboelectric), thermoelectric, or thermionic.

Much experience has been gained in the use of conventional rotating equipment and abundant design data are available. However, Rankine cycle turboelectric systems decrease in efficiency rapidly at power output levels below one kilowatt. Furthermore, the reliability of rotating machinery is difficult to predict for unattended operational uses extending more than a few months in time.

Thermoelectric conversion offers exceptional reliability in that the process involves no moving parts, as well as attractive safety features. The present state of the art in thermoelectricity is sufficiently advanced to encourage its immediate use.

The physical basis of thermoelectric conversion is defined by the Seebeck effect, known since 1821. Its most familiar application is in thermocouples. When two dissimilar metals are connected to form a closed loop, and the ends are at different temperatures, an electric current will flow. One of the elements, the "N" type, has surplus electrons; the other element, the "P" type, is electron deficient. The surplus electrons and deficiencies or "holes" are the charge carriers and migrate in the direction of the decreasing temperature. Thus the deficiencies in the "P" or positive element move from the hot to the cold junction, while in the "N" or negative element, the electrons move from the hot to the cold junction.

The power and voltage available from a thermocouple (or several thermocouples connected in series or parallel) depend upon the thermoelectric properties of the materials used, the temperature difference between the hot and cold junctions and the number and dimension of the couples.

Electrical power at useful voltages and currents has been made posible only in recent years by the development of semi-conductors which exhibit the Seebeck effect. A typical pair ("N" and "P") of these elements will produce 0.1–0.2 volts and permit a current of 1 ampere to flow in a closed circuit when a temperature differential of 700° F. is maintained between the hot and cold junctions. A conventional bimetallic thermocouple would produce only a few milli-

volts and negligible current under the same temperature condition.

Thermionic conversion holds great promise, but is in an earlier state of development relative to thermoelectric conversion. The process involves the application of heat from an external source (e.g., a radioisotope capsule) to raise the temperature of a cathode to the point where electrons are emitted. By placing a collector close enough to the anode and maintaining a vacuum between the two electrodes, an electrical current can be made to flow through a closed external circuit. Very high power densities and conversion efficiencies are theoretically attainable.

The performance of all devices converting thermal to electrical energy is ultimately limited by the so-called Carnot efficiency, which is a function only of the temperatures at which the heat is applied to the device and at which the residual or unconverted heat is rejected to the external environment.

The surplus heat may be removed by radiation, conduction, or convection. For space applications, only radiation can be used and radiator design problems frequently become the great barrier problems in designing power supplies. For terestrial applications, much less rigorous weight requirements usually exist and in maritime systems, the most efficient of all heat rejection system, removal to the external water is available. Hence, in applications other than space devices, this problem does not constitute a major difficulty.

THE RADIOISOTOPE HEAT SOURCE

Heat generation in isotopic power systems stems from containment of two major types of radioactive source materials. The first is the waste material arising from the controlled fission of uranium and the second is produced by irradiation of suitable target materials in nuclear reactors. Each type of source material has distinct advantages for specific misions. Fissions wastes are recognized as a major projected disposal problem of the nuclear power industry and predictions for the year 1975 indicate the accumulated formation of 12 billion curies. Since this quantity of fission products amounts to about 50 megawatts of power, it appears obvious that generation of useful power from these wastes will satisfy at least two important needs, namely, power generation and waste disposal.

Fuel selection for the radioisotopic power source is governed by the manner in which the power supply will be used. Variables to be considered are:

(1) Power density in watts per gram.
(2) Half-life.
(3) Cost.
(4) Availability.
(5) Shielding.
(6) Safety in use.

General analyses may define the first four parameters, with the remainder reflecting the specific mission or application requirement.

More than 200 radioisotopes are formed in the fission process, but it is reasonable to consider only those with half-lives longer than 100 days as potential fuels for energy conversion systems. This limits the number to a few. Furthermore, it is estimated that a

thermal output greater than 0.01 watt per gram is required to keep the heat source to a practical size. This criterion is necessary to convert the heat efficiently to useful work and to minimize the shielding requirements necessary to allow personnel access to the power unit area. Gross fission products in fused salt form, after calcination processing, do not meet these criteria in terms of power density and chemical stability at elevated temperatures.

Table I provides data on those isotopes which are under the most intensive investigation at this time. The first three are fission products and are principally beta particle emitters. Information shown on specific power of the fission products was obtained as a result of work performed at the Oak Ridge National Laboratory (ORNL), and fuel availability is predicated on the capacity of a separation pilot plant recently completed there. Only those radioisotopes which can be processed by ORNL in sufficient quantities to produce power are considered. As demands for larger quantities of radioisotopes develop, additional separation facilities can be made available at the Hanford Facility.

There are some specific applications where fission products are seriously limited. These limitations are due to the size and weight of the shielding that must be used to allow biological specimens to exist for long periods of time in close proximity to these sources, or to prevent radiation damage to electronic components or film used during the specific mission. These problems may be circumvented by using alpha emitters as the heat source. With the proper selection of these alpha emitters, a kilowatt of heat can be safely contained in a three-cubic-inch volume.

After extensive examination of the alpha emitters available, it appears that there are only three isotopes that have merit as heat sources. These are Curium 242, Polonium 210, and Plutonium 238, as shown in Table I. Potential availability and cost, plus the lack of high energy gamma radiation were the deciding factors in the selection of these three isotopes.

Two of these three isotopes, curium and polonium, are in the short-life, high-power category, while Pu–238 will answer the problem of long-lived heat sources.

TABLE I.—*Specific Power of Various Isotopic Power Sources*

Isotope	Principal radiation	Half-life	Compound	Practical compound density (g/cc)	Specific power [1] (watts/cc)
Ce–144 [2]	beta	285 days	CeO_2	6.4	12.5
Pm–147 [2]	do	2.6 years	Pm_2O_3	6.6	1.1
Sr–90 [2]	do	28 years	$SrTiO_3$	4.85	0.54
Cm–242	alpha	163 days	Cm.30Ni	8.7	28.5
Pu–238	do	86 years	PuC	12.5	6.0
Pu–238	do	86 years	Pu	16.0	0.3
Po–210	do	138 days	Po	9.4	1,325.0

[1] Specific power based on actual compounds as separated today in various facilities of the AEC.
[2] Fission products.

Two other important areas to consider in fabricating these power packs are cost and availability. Table II is based on the best estimates of the Division of Production of the U.S. Atomic Energy Commission.

These are predicated on isolating only one isotope in the Hanford Facility. If uses are found for more of these fission products, the cost will be reduced.

TABLE II.—*Cost per Watt of Isotopes Used for Isotopic Power*

Isotope	Cost	
	Next year	Future years
Ce-144	[1] $87	$14
Pm-147	[1] 2,990	1,630
Sr-90	[1] 455	23
Cm-242	[2] 80	[2] 45
Pu-238		[3] 1,600
Po-210	1,280	1,280

[1] Cost is present ORNL fission product cost compared to ultimate cost as projected for Hanford Facility estimated by U.S. Atomic Energy Commission, Division of Production. Costs are based on maximum capacity of each plant.
[2] Martin Co. estimate.
[3] Estimated cost.

OPERATIONAL SYSTEMS

The tremendous potential uses for energy released from isotopes are just beginning to materialize. Use of radioisotopes in electrical power generation in the range of 1 to 500 watts enables electrical or electronic designers to consider devices and missions or programs never before possible. Besides being able to produce electricity, several devices utilize the surplus heat from radioisotopes in auxiliary useful services.

Investigations have proven that direct conversion power supplies can be built with extreme ruggedness and reliability and can safely be used in space, surface and underwater applications. These devices are capable of power generation over an extremely long period of time (6 months to decades).

Specific applications now under intensive study include:

Automatic Weather Station

Automatic weather stations have existed in various stages of development and operation for approximately 20 years. Such agencies as AFCRC, NBS, NRL, NEL, the Signal Corps, and the Weather Bureau in this country, as well as their counterparts all over the world, have been seeking satisfactory methods for the instrumentation and powering of remote unattended weather stations.

Automatic weather stations are needed for research in remote areas as well as for filling gaps in the synoptic network in such areas as—

(1) Arctic and subarctic.
(2) Midlatitude mountain regions.
(3) Deserts.
(4) Tropical reefs and jungles.
(5) Ocean areas.

A network of automatic weather stations operation on a synoptic basis will provide valuable meteorological information leading to improved 72-hour forecasts and five-day outlooks.

The advent of the radioisotope-fueled thermoelectric generator has made possible the design of an automatic weather station for two years operation without attendance or maintenance. The power for

the weather station is provided by a thermoelectric generator fueled by a 100-thermal-watt Strontium 90 heat source (Figure 1). The generator produces five electrical watts and continuously charges a nickel-cadmium battery. The battery has a rated capacity of approximately seven times the discharge requirements to insure a two-year minimum life for the complete power source package. The station will transmit weather data every three hours, so a conservative rating of 470 watt-minute every three hours has been established for the power source. This power is supplied to the weather station at a nominal voltage of 12 vdc. The approximately 95 thermal-watts of rejected heat are used to warm the weather station instrumentation and radio transmitter (Figure 2).

All operations of the weather station, including shutdown, will be controlled by a sequencer after initiation by the station master timer. The first signal input to the transmitter will identify the weather station. Following this, the transmitter will be keyed by binary 1's and 0's representing the digital values of the temperature, barometric pressure, and wind direction and speed. The entire sequence of information will be transmitted twice. The time required for the complete radio transmission, including repeat, is approximately 17 seconds.

The transmitter provides two 460-watt peak output signals on two separate radio frequencies at approximately 2.5 mc. and 5.0 mc. This diversity will improve the reception reliability, since the propagation path will vary widely in two years.

All circuits except the high power radio frequency output stages employ transistors which are operated from the 12-v battery to eliminate a secondary supply voltage.

Decoding at the audio output of each receiver is accomplished by driving two selective band-pass filters tuned to the proper audio frequencies. The detected outputs of the filters are then fed into a conventional recorder to reproduce the original digital binary word representing the meteorological data.

The station is equipped with two half-wave radio antennas, one for each transmitting frequency, supported by three masts. The common antenna mast is placed near the housing containing the instrumentation and transmitter and provides mounting brackets for the wind vane, the anemometer, the shielding temperature bulb and their associated data coding devices (Figure 3).

100 Watt Land—Or Sea-based Generator

The AEC's Office of Isotopes Development has contracted for a study giving consideration to two 100-watt (electrical) generators satisfying the requirements of safety, reliability and efficiency. The first related to an unattended land mission and the second, an undersea application, both having dependable operational lives of 8 to 10 years. The specifications imposed on the design are listed in Table III.

TABLE III.—*Design Specifications for Strontium-90 Generator*

	Land-based	Sea-based (removable shield)
Size (inches):		
Height	20¾	18.
Outside diameter	22½	17.
Approximate weight (pounds):		
Storage	1,500	1,600.
Operation	1,500	600.
Thermal input (watts)	2,080	1,500.
Electrical output (watts)	100 at 12 v.d.c.	100 at 12 v.d.c.
Designed thermal to electrical efficiency (percent)	5	6.7.
Operating temperature (°F.):		
Hot junction of thermocouples	960	835.
Cold junction of thermocouples	260	135.
External shield	160	80.
Sr-90 fuel load (curies)	320,000	280,000.
Heat elements	(Sr-90) (TiO_3)	(Sr-90) (TiO_3).
Thermocouple material	Lead telluride	Lead telluride.
Total shielding (inches of Hastelloy)	3¾	1¾.
10-year power (tons of batteries)	80	125.

A problem of primary importance was faced in developing a suitable fuel form of radiostrontium having a high melting point, extremely low solubility in fresh or seawater, resistance to radiation damage over the generator life, high strontium density, good thermal conductivity and good workability. Of the many materials thoroughly examined and tested, strontium titanate ($SrTiO_3$) satisfactorily met these specifications with present day technology, as shown in Table IV.

TABLE IV.—*Properties of $SrTiO_3$*

Melting Point (°F) : 3038
Solubility :
Fresh Water (60° C) : None detected
Sea Water (60° C) : 10 parts per billion
Strontium Density (gm/cc) : 2.44
Thermal Conductivity (Btu-ft/ft²-hr-°F. at 212° F.) : 2.78 (at 1200° F., decrease is 28%)
Compressibility (gm/cc) : 92% theoretical (5.11 gm/cc)
Radiation Damage : Under test

The next phase of development imposed even further safety restrictions on this isotopic heat source, namely, that of finding a containment material of commensurate or greater insolubility than by fuel form. Hastelloy C (Haynes Stellite Company) tested for more than 10 years at Wrightsville Beach Testing Station, North Carolina, under the actual conditions of seawater corrosion, is consumed at the rate of 0.0001 inch per year, with no evidence of pitting or crevice corrosion. One-quarter inch of Hastelloy C cladding on the fuel would in itself, provide resistance against seawater for an estimated five centuries. By this time almost all the Sr–90 would have been converted to stable Zr–90, presenting no radioactive hazard.

The high density, fired, ceramic pellets, encased in Hastelloy C cladding, are further enclosed in a "heat accumulator" block of either Hastelloy or tungsten if reductions in size and weight are desired, and then they are sealed. Lead telluride thermoelectric materials are adapted to the right cylindrical block, making it possible a reliable and silent power supply.

Figure 4 depicts a model of the generator in a housing suitable for land-based operations.

Air and Space Applications

The possible applications for an isotopic power plant in this category are unlimited. Every space vehicle requiring a long-lived, light, reliable power plant in the range of 1 to 500 watts is a potential user of an isotopic power unit. Such uses need not be limited to the power output of the power plant itself, providing the power requirement is cyclic. In this case, the energy may be stored in a battery bank and released in short bursts of high power.

The first such power unit designed for space application was a "proof of principle" device designated SNAP–IIIB. An artist's concept is shown in Figure 5.

Polonium 210 was selected as the fuel for the generator because of its high specific alpha and low gamma activities, facilitating ease of handling and demonstration.

Other isotopes show more promise for certain operational uses, however. As a matter of fact, the size and design of the SNAP–IIIB is such that Curium–242 could be substituted for Polonium 210 with little difficulty. Although Curium–242 would extend the half-life of the unit only slightly (from 138 to 162 days), this isotope has other advantages. Its gamma emission is even lower than that of Polonium 210; its power output per unit of volume in usable form is almost three times as great; and the fact that it can be used in solid form makes it easier to contain safely at high temperatures than volatile polonium. The latter may be more desirable for certain applications.

Plutonium 238, of course, would increase the life of an operational unit to decades, but the lower power density would require some increase in the size of the generator.

The polonium–210 for SNAP–IIIB was supplied in encapsulated form. Each of two stainless steel cylinders contained about 800 curies of activity. These were closed with tapered plugs. Each plug was sealed by heliarc welding with 100% penetration. The capsules were carefully tested for alpha activity and helium leakage. The two cylinders were inserted into a close-fitting third canister which was sealed and tested using the same techniques. The third canister was enclosed in a molybdenum core which had been flame coated to prevent oxidation and sealed with a stainless steel tapered pin plug under helium pressure. The latter provides a thermal bond between the steel capsule and the molybdenum core. Closure with a pin plug obviates the need for a high temperature seal which could adversely affect the heliarc welds. Tapering the molybdenum block ensures good thermal contact with the hot junction ring of the thermoelectric converter.

Situated radially about the contained heat source are 27 couples of doped lead telluride elements. These elements are doped with bismuth or sodium to provide N- and P-type semiconductors. One N-type and P-type thermoelement comprises a couple, and all are connected in series. Each of the elements provides a parallel path for heat flow from the heat source to the container-radiator.

Table IV lists many of the important performance characteristics of the SNAP–IIIB unit. However, this device was constructed for "proof-of-principle" and little attempt was made to minimize weight. Simple design changes and optimal selection of materials in the container would reduce the weight from the present four pounds to less than three without seriously affecting power output or efficiency.

TABLE IV.—*SNAP–IIIB Characteristics*

Dimensions	4.75-in diameter, 5.5-in height.
Weight	4 pounds.
Source	1,700 curies (0.38 gram) of Polonium 210.
Thermal output	60 watts.
Electrical output	3.3 watts to optimum load of 1.7 ohms.
Efficiency	5.5 percent.
Total electrical power output over 280 days (approximately 2 half-lives).	10,000 watt-hours.
Conventional battery equivalent (over 2 half-lives).	160 pounds of zinc-silver cells.
Open circuit voltage	5.0 volts.
Closed circuit voltage	2.5 volts to 1.7 ohm load.
Thermoelectric elements	Lead telluride—P-type doped with bismuth, N-type with sodium.
Hot junction temperature	496° C.
Cold junction temperature	107° C.
Copper shell temperature	99° C.
Dose rate at shell surface	500 milliroentgen per hour.
Dose rate at 1 foot	50 milliroentgen per hour.
Dose rate at 5 feet	1 milliroentgen per hour.

THERMAL APPLICATIONS

As distinguished from those concepts in which the heat produced by radioisotopes is converted to electricity, there are novel applications of isotopes in which the heat emitted is employed directly.

A steam-operated repetitively sounding horn is illustrated in Figure 6. It might be employed as a warning horn for underwater or coastal obstacles, or as a foghorn with the incorporation of a suitable sensing device.

Early in 1960 success was achieved in heating the cathode of a vacuum tube using a radioisotope heat source. Proper operation of the triode as an audio frequency amplifier was demonstrated.

A planar element, ceramic vacuum tube was used in this demonstration. The tube was built with one face of the cathode exposed for installation of the radioisotope heat source. A drawing of the device is shown in Figure 7.

The heat source for the demonstration tube was 300 curies of Polonium–210 encapsulated in a double stainless steel container 0.31 inches in diameter and 0.625 inches long. Two rotatable cylindrical reflectors, slotted to provide a variable heat radiation system, are used to maintain constant cathode temperature even though the heat output of the decaying radioisotope is continually decreasing.

A more conventional application of isotopic heat is for use in winterizing equipment for use in polar regions. Work has been completed in determining the feasibility of winterizing dry cells for arctic operation. A preliminary sketch of a battery (Figure 8) shows how thermal energy from isotopes, used in combination with proper insulation,

keeps the batteries operating in their optimum environment in temperatures down to −65° F. This design compensates for the excess heat generated by internal resistance of the batteries by using a thermal shorting system which operates at 80° F. Figure 9 illustrates a method for heating a wet cell vehicle type battery.

Similarly, isotopic heat could be used to winterize various components of vehicles, to heat shelters in barren areas, to heat standby generators or other emergency equipment and to perform a number of other important functions.

CONCLUSIONS

Uses of radioisotope power units become legion when one appreciates the economic service that can be rendered by devices that furnish several thousand watt-hours of electrical energy per pound of generator weight. Radio power supplies are eminently suited to run a whole gamut of remotely located devices such as radio beacons, fallout and fire warning alarms, infrared forest fire detectors, sea lane markers, iceberg and reef identification buoys, navigational buoys, telephone repeaters, portable x-ray units, survival and emergency equipment, radio-altimeters and sonobuoys. The sorely needed empirical investigation of the oceans and ocean bottoms of the world should generate an immediate need for radio-nuclide power for submerged instrument packages. The long life obtainable should be particularly attractive to oceanographers, for these power sources will permit integrated looks at the many ocean environment parameters now only checked intermittently.

These self-contained sources of energy are rugged and reliable, they hold strong promise of enabling man to probe the environment of the planets of the solar system and to prepare himself for the conditions to be encountered on his arrival. Thus, isotopic power may prove invaluable to all phases of scientific and technological endeavor.

Information contained in this report was obtained from the following sources:

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IMPACT OF RADIOISOTOPES ON THE LIFE SCIENCES

By the U.S. Atomic Energy Commission

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Research in Biophysics and Biochemistry.
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Impact of Radioisotopes on the Life Sciences

Scientists engaged in life science studies have found isotopes of great value in work on biophysics, biochemistry, and oceanography and marine biology. Tritium labeling has permitted studies to be made at the molecular level within cells in efforts to characterize chromosomal activities and cell division. Tracer methods also have permitted sensitive measurements of the effect of radiation on individual cell components. In oceanography: tracer techniques are used to evaluate the metabolism of various elements by water organisms; carbon 14 and tritium provide tools for study of the chelation and release of normal organic compounds found in the sea and the capacity of marine organisms to use nutrient material; and permit study of the dispersal of fertilizer in natural water, internal currents and mixing, and productivity. The studies described here indicate the scope of radioisotopes usage in these fields.

RESEARCH IN BIOPHYSICS AND BIOCHEMISTRY

Studies of Nucleic Acids

There now is fairly convincing evidence that radiation-induced genetic changes are a result of either chemical or spatial alterations in the deoxyribose nucleic acid (DNA) of the cellular genetic material, the chromosomes. Some alterations are associated with gross aberrations involving whole chromosomes or large portions of them. Others which involve more subtle changes within the genes which comprise chromosomes are called point mutations. Further, it appears that DNA specifies the formation of ribose nucleic acid (RNA) and RNA then participates in protein formation. The proteins, through their ability to catalyze chemical reactions, control cellular metabolism so that eventually they are involved in duplication of the DNA that is incorporated into new chromosomes, thus completing the cycle.

Radiation received during that portion of the cell lifetime prior to the protein-to-DNA part of the cycle appears to be the most effective in initiating damage. Experiments now in preliminary stages indicate that RNA synthesis must occur before the mutation is permanent, since interruption of the synthetic process for a certain time,

or the destruction of certain abnormal intermediates produced by the irradiation before RNA synthesis occurs, essentially prevents the mutation from becoming established.

Many tritium-labeled precursors of RNA, among them cytidine, are being used to study RNA metabolism in actively dividing cells. With continuous treatment, it was found that radioactive material first appears in the nucleolus (a small spherical body within the cell nucleus) and later in both nucleolus and the cytoplasm outside the nucleus. The finding that RNA synthesized in the nucleus is limited to only a part of the nucleus, namely the nucleolus, is of major importance in connection with the theory that RNA picks up genetic "information" from the DNA of the genes. If this hypothesis is correct, RNA must be associated at some time with the genes or chromosomal portion of the nucleus.

Other important studies underway at this time are aimed at determining the sequence in which synthesis of protein, RNA, and DNA occurs following damage from radiation or any other mutation-causing source. It is important to know whether the DNA which has been damaged by radiation serves as a template for future production of RNA and protein, or whether some other sequence governs. The understanding of this problem is basic to understanding and developing therapeutic measures against radiation damage.

The studies described are directed at unravelling the specifics of the DNA-RNA-protein cycle. Of equal radiobiological importance is an understanding of the manner in which chromosomal changes are eventually expressed in the form of an altered cellular metabolism. This problem has been attacked anew by the use of DNA taken from bacterial cells capable of growing on a medium containing only mineral salts and a carbon source (referred to as wild type cells). When this DNA is given to mutant strains which require some such factor as an amino acid, in addition to mineral salts and a carbon source, the mutant responds as does a wild type cell. Recent studies have shown that the transformation of the mutant type of growth to the wild pattern probably involves induction by the wild type DNA of the ability to produce a specific enzyme.

Radioautography

Localization of radioactive materials in cells and tissues can be observed with the isotope technique termed autoradiography.

In this kind of autoradiography, photographic emulsion is placed in contact with a specimen containing radioactivity and stored in the dark. The radiation, passing through the emulsion, sensitizes silver bromide granules so that they can be reduced to metallic silver by a photographic developer. The result is a pattern of silver grains lying above the specimen and indicating distribution of the radioelement.

Tritium (H3) decays to helium 3 with a half-life of 12.3 years. The beta particle produced in this process is one of the least energetic known, having an average energy of only 5,700 electron volts. The resulting short range of tritium's beta particle, while presenting difficulties in its detection, is of decided advantage in autoradiography because of the high resolution of detail which it permits. Even the most energetic beta particle from tritium can penetrate only 6 microns (6 thousandths of a millimeter) in water or tissue, and only 2 microns

in photographic emulsion. However, autoradiographic resolution is even better than this range might indicate because most of the beta rays from tritium have much less energy, and because, in addition, only the two-dimensional projection of their range is seen. Therefore, essentially all the silver grains activated by tritium lie clustered within a micron of the structure in which the radioisotope occurred.

Tritium-labeling of specific compounds of biological importance now has developed to the point that almost any compound of interest can be secured at reasonable cost. The use of tritium in particular compounds that selectively go into the chromosomes has provided one of the most powerful tools to the cytogeneticists since discovery of the electron miscroscope. In addition, other tritium-labeled compounds have been used to study the biosynthesis of protein, deoxyribose nucleic acid (DNA) and ribose nucleic acid (RNA).

Until development of tritium-labeled thymidine, it was difficult to study the method by which chromosomes duplicate their genetic material before the cell divides, and contribute one half to each daughter cell. Thymidine finds its way almost exclusively into the DNA of the chromosome. This technique has demonstrated that the synethesis of new DNA occurs only at very particular stages in cell division.

In these experiments, root tips of the English broad bean are incubated for a definite period of time in solutions containing the tritiated compound, and then are removed. The cells then are separated and fixed onto a microscope slide for autoradiography. Single strands of chromosomes can be seen. These studies reveal that the newly formed DNA is quite distinct from the original DNA and that the two maintain their integrity during division.

The new DNA is distributed equally to the daughter chromosomes and therefore it must be assumed that the same is true of the old DNA. Furthermore, it has been observed that if the cells are taken from the solution containing tritiated thymidine after one replication of the chromosomes, and then placed in a nonlabeled thymidine solution, each chromosome regularly produces one labeled daughter and one daughter completely free of the isotope in nearly every case. Further study of the collected data indicates that the chromosomes synthesize the new DNA from the ends toward the middle or the centromere.

It is expected that this powerful technique of using tritiated thymidine will be expanded to reveal many internal workings of the cell.

Physical Cytology

In addition to radioautography, other methods can be utilized to localize the cellular regions within which various processes occur. By using highly localized beams to irradiate only selected portions of cells, information can be obtained about many potential explanations of cellular damage. These techniques have been adapted to study the genetic changes described previously. In general, the procedure has been to determine how exposure of a restricted cell component to either ionizing or ultraviolet radiation disturbs the normal steps in the duplication of chromosomes and their distribution into daughter cells. From an understanding of the control exerted on cell division by individual cell components, the importance of each in producing radiation damage can be assessed. Breaks in chromosome chains are

undoubtedly the most common form of aberration and are probably initiated prior to the beginning of cell division. Details of other pertinent effects produced during cell division include the following:

Paling.—If only a restricted portion of a single chromosome is irradiated with a sufficient dose of ultraviolet or protons, that region becomes pale when viewed with either visible or ultraviolet light. The loss in density is proportional to the total dose delivered but does not develop if the whole chromosome set is exposed. The paling apparently represents a loss of nucleic acid from a protein backbone which remains intact. However, in the case of ultraviolet, the initial absorption of the radiation energy responsible for this loss very likely occurs in the protein.

Stickiness.—When doses insufficient for paling are absorbed in localized regions of the chromosomes, they will adhere together when normally they should separate during cell division. This aberration can result in an incomplete set of chromosomes in one daughter cell. Similar effects can result from destruction of a centriole, spindle or kinetochore, all of which are involved in separating the individual members of each chromosome pair prior to cell division.

Spindle.—Destruction of a spindle is an indirect result of irradiation of the cytoplasm rather than of the spindle itself. In fact, irradiation of the cytoplasm of a closely-joined sister cell causes the damage. The amount of ionizing radiation required for this effect varies greatly depending upon the type of cell involved. This effect may contribute significantly to radiation damage in some cases.

Kinetochore.—In contrast to the spindle, the kinetochore (the point of attachment of the spindle to the chromosome) is destroyed by radiation absorbed directly. Its destruction leads to a random, uncoordinated drifting of whole chromosomes rather than the usual separation of the individual chromatids.

Dosage values for the above effects produced during cell division are combined with data for the number of breaks produced per unit of dose absorbed later. Unfortunately some of the data are accurate only within a factor of two and data are incomplete for the types of effects listed, or for a given type of cell with only one kind of radiation, or for exactly identical irradiation conditions. Until more complete data are available the table given here is meant only to give a very general idea of the relative importance of each type of effect in producing radiation damage.

Range of Dosages Required To Produce Different Chromosome Aberrations

Effect	Type of cell	Radiation	Dose required to produce an effect in 50 percent of the cells
Breaks	Human fibroblast	X-ray	40 r.[1]
Do	Human kidney	do	165 r.
Do	Tradescantia microspores	do	150–300 r.
Spindle destruction	Trillium microspores	do	150 r.
Stickiness	Salamander heart	Protons	3×10^{-5} ergs/u^3 of irradiated chromosome.
Kinetochore destruction	do	do	10^{-7} ergs, 1000 r.
Paling	do	do	4x10 ergs, 400,000 r.
Spindle destruction	do	do	0.2 ergs/cell 2×10^3 r.

[1] Roentgens.

Another technique used for irradiation of specific cell components is to break open cells, and then isolate pure preparations of the components. These can then be irradiated and effects observed. For example, the details of radiation effects on the cell structures termed mitochondria (which carry out certain of the energy-producing reactions in cells) can be studied in this way. Similar studies have been carried out with the green chloroplasts of plants, the cell structures which absorb light energy and carry out photosynthesis.

By combining tracer methods with the above techniques, sensitive measurements of the effect of radiation on individual cell components can be made. For instance, one sequence of phosphorylating reactions necessary for the synthesis of DNA in cell nuclei is reported to be blocked by 100 roentgens. By using labeled phosphates, experiments are now under way to separate these reactions from cellular structure and study their radiation response.

Diffusion Studies

Some cells normally exclude certain atoms while selectively concentrating others. This selectivity can be modified by numerous agents, including radiation.

Radioactive isotopes must penetrate into cells and be retained there in order to affect the organism. Penetration is controlled by the permeability of the cell wall and membrane. Once inside, soluble materials can be selectively concentrated either by being bound to some cellular structure or by being incorporated into large molecules. Isotopes play a prominent role in evaluating for a variety of cell types the relative roles of membrane permeability and internal concentration in the case of individual elements.

In addition, synthetic membranes, each capable of selectively passing ions from only one element are in the preliminary stages of development. These can be utilized for analytical tests and to simulate the selective properties of living cell membranes. Perhaps they will permit ultimate development of techniques for removing fission products from water and food.

OCEANOGRAPHY AND MARINE BIOLOGY

Although study of the oceans is an ancient activity, no data are available concerning large portions of the Pacific and Indian Oceans and only minimal information exists about other portions of the sea. The initiation of research in oceanography and marine biology using radioactive isotopes consequently has been of great significance. As part of its responsibility to protect health and safety, the Commission has obtained and maintained information concerning the fate of radioisotopes in the ocean as released by weapons tests. Certain discoveries, such as the finding that plankton concentrate mixed fission products, have led to various marine applications of radioactive isotopes. A few examples of these applications are given in the following sections.

Metabolism

One of the most difficult problems in marine biology is to evaluate the metabolism of various elements in water. Sponges, diatoms and other organisms concentrate silicon, fishes concentrate calcium, shellfish concentrate cesium, and lobsters concentrate cobalt. These gen-

eralities have been known for a long time. For the most part, chemical and physiological processes of the body require chemical elements to form compounds without discrimination as to the isotopic composition of the elements. Living tissues accumulate chemical elements to different degrees.

Radioisotopes have made it possible to tag organic materials and to release radioactive isotopes in water in order to study their uptake through various steps in a food system. The digestability of plankton organisms, the acceptance of various size particles by shellfish, the rates of feeding of filter feeding organisms, the function of the blood in transportation of various chemicals, the relative passage of chemicals through body surfaces, and other such topics can be studied with greater ease with radioisotopes. It is also possible to study the transfer of nutrients and to gain information on the efficiency of utilization of various compounds.

The tagging of marine organisms with radioisotopes makes it possible to identify populations as they make vertical or horizontal migrations and to study their normal reactions under field conidtions.

Sedimentation

The mechanisms whereby organic materials adhere to soil particles are extremely difficult to determine. Clay minerals and other fine particles have a high capacity to absorb organic and inorganic cations. Many complexing, or chelating, organic chemicals have been reported from natural waters and sediments. For example, aspartic acid may chelate with calcium, manganese, strontium, cobalt and other cations. Although a substantial amount of research has been accomplished concerning the exchange capacity for various clays and for soils, information is far from complete, especially for marine sediments.

Carbon 14 and tritium isotopes provide tools for study of the complexing and chelation of organic radioactive cations. With the use of carbon 14, a rapid, reliable, and efficient means is provided for the analysis of adsorption phenomena. Tritium, with its ease of labeling, gives an inexpensive mechanism for study of chelation and release of normal organic compounds found in the sea. The labeling of decomposed planktonic organisms, which supply the major amount of available organics, can be readily accomplished.

Studies of the attachment of such nuclides is being followed by further work which is concerned with the capacity of marine organisms to strip nutrient organics from sedimentary particles.

Distribution of Elements

Radioisotopes have provided much valuable information concerning the dispersal of fertilizers in natural waters. Radiophosphorus can be added to waters and identified in quantities below detectable limits by ordinary methods. Field studies using phosphorus 32 have confirmed the suspected recycling of organic phosphorus through aquatic food organisms. Rates of dispersal of fertilizers have always been of concern in waters. The use of phosphorus 32 provides a tool for research on this problem.

Field Studies

Various dyes have been used to tag small components of ocean water as a device to study internal currents and mixing. Such studies have been of restricted value because of the large volumes of dye that

must be used and the dissipation of the chemical to below a detectable level.

Several radioisotopes offer real promise of providing more widely applicable information. For example, carbon 14 from the atmosphere approaches equilibrium in the surface water of the sea. Ocean water generally sinks in the polar regions and moves along the bottom toward the equator. Since the carbon 14 tends to disappear with a half life of about 5,600 years, its abundance changes as compared to the stable isotope, carbon 12. Computations of the relative amount of change of the carbon 14-carbon 12 ratio with time provide information concerning the age of a water sample. Such data also indicate the length of time involved since the water left a polar region. Such data do not reveal, however, the path the water sample has followed.

More definitive uses of such isotopes as strontium 90 and zinc 65 have come from the weapons test area. Diffusion of radioactive nuclides from the test site may be followed accurately by locating the leading edge of the diffusing materials and studying its patterns with depth and time.

Experimental release of radioisotopes from a point source at various depths in the sea, above and below layers exhibiting changes in density and temperature, offer unprecedented opportunity for studies of mixing and diffusion processes.

Productivity

Another way that radioactive isotopes may contribute to scientific knowledge of the oceans is their application to the study of economic productivity of the oceans. Tagging living organisms with radioactive nuclides provides a means for study of rates of production of individual species of organisms. Such studies may be accomplished under field conditions with the use of light and dark bottles or in laboratory closed systems.

TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

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With this letter I enclose a report on the "Basic Research in the Physical Sciences" prepared by the Commission's Division of Research. The Review Staff's attention is called to the printed record of the Hearings on the Physical Research Program, February 3–14, 1958, before Joint Committee's Subcommittee on Research and Development. Statements of a summary nature on the various subprograms of the Atomic Energy Commission's physical research program may be found on the following pages of this volume, a copy of which is enclosed:

Chemistry: Dr. Seaborg, pp. 14–23.
Materials: Dr. Seitz, pp. 38–42.
Low and Medium Energy Physics: Dr. Williams, pp. 335–338.
High Energy Physics: Dr. Alvarez, pp. 530–534.
High Energy Accelerators: Discussions by various scientists, pp. 645–710.
Role of Computers and Mathematics in nuclear research: Drs. Metropolis and Richtmyer, pp. 629–644.

BASIC RESEARCH IN THE PHYSICAL SCIENCES

By the U. S. Atomic Energy Commission

The U. S. Atomic Energy Commission's program of research in the physical sciences includes basic investigations in the fields of physics and mathematics, chemistry, and metallurgy and materials. These investigations are undertaken for the purpose of discovering natural laws relevant to the Commission's responsibilities for the development, use, and control of nuclear energy. In retrospect, almost every advance made in nuclear energy capability can be traced to basic research investigations of the type conducted under this program.

The Atomic Energy Act of 1954 provides the legal foundation upon which all the Commission's activities are based. It sets forth the AEC's basic responsibility for research and development. The Act provides for a program of conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress. It directs the AEC to exercise its powers in such a manner as to insure the continued conduct of research and development and training activities by private or public institutions or persons, and to assist in the acquisition of an ever-expanding fund of theoretical and practical knowledge.

In carrying out its assignment as outlined in the Atomic Energy Act, the Commission's responsibilities in physical research may be stated as follows:

(a) to....Provide a broad base of scientific facts, interpretation and theory about the physical aspects of nature,

(b) to....Develop some of the emergent ideas from this base until they can be evaluated properly and transferred to society for exploitation,

(c) to....Undertake specific investigations when our skills and facilities are unique, and, as an important byproduct

(d) to....Train additional scientists and engineers so that scientific manpower will be available in future years for the continued assaults on the many problems which need to be pursued.

Almost all of the Commission's research is accomplished through contract with private organizations, in many cases with academic institutions.

The facilities of the Commission at the Oak Ridge, Brookhaven and Argonne National Laboratories, the Los Alamos Scientific Laboratory, the Lawrence Radiation Laboratory, and the Ames Laboratory, are government-owned, but contractor operated. With the exception of Oak Ridge National Laboratory, they are all operated by a university or a group of universities. In addition to the work being carried out at these research centers, the AEC has a substantial contract research program at colleges, universities and other private research laboratories all over the United States.

In addition to sponsoring research in AEC's major research centers and at universities, colleges and other research institutions, the Commission contributes to the design and construction of complex research machines and other special facilities for research.

Work in physics and mathematics covers research relating to high energy physics, nuclear structure and neutron physics, extra-nuclear properties of matter, physical methods of isotope separation, mathematics, and computer development. The major effort centers around attempts to learn all that can be learned about the fundamental properties of nuclear

matter. In these studies it is necessary to construct and operate rather elaborate facilities. These facilities range from the simplest laboratories with modest equipment to such highly complex research machines as multi-billion electron volt particle accelerators.

High energy physics is one of the most active fields in contemporary science. Extensive progress has already been made and there is excellent promise of a rapid expansion of knowledge of the properties of elementary particles. Research in this field centers around accelerators capable of accelerating electrons or protons to energies of one billion electron volts or more. At present, there are four such accelerators in operation in the United States, and four more will come into operation within the next few years. Similar research machines are in operation or under construction in other parts of the world. Many hundreds of scientific, technical and supporting personnel are busily engaged in these studies.

Computer development and mathematics research provides research support behind the computing services at the Commission's facilities. The complexity of the AEC's varied programs has led to considerable dependence on the use of high speed automatic computers in many phases of its activities. Research in the fields of computer technology and servomechanisms is becoming increasingly significant in connection with data taking, analysis, and instrument control.

Fundamental chemistry research includes investigations in the areas of nuclear chemistry. Considerable emphasis is placed on the nuclear and chemical properties of the very heavy elements, radiochemistry, radiation chemistry, general physical and inorganic chemistry, high-temperature and materials

chemistry, and analytical chemistry.

The Commission's chemistry research program is also devoted to such problems as solvent extraction and ion-exchange techniques for possible use in the production of special nuclear materials. Other subjects include: analytical techniques for process control and methods for producing usable amounts of rare earth salts, chemical isotope separations, and the preparation and purification of special research materials..

Metallurgy and materials research activities include the production, treatment, and properties of materials, alloy theory and the nature of solids, and the effects of irradiation on materials. Basic investigations of the solid state are becoming increasingly important. Such studies will provide a foundation of knowledge for future utilization and are a prerequisite for the fundamental understanding of the influence of radiation on materials.

Solid state studies include such areas as alloy theory, electronic structure of solids, mechanisms of atom movements in solids, the origin and influence of lattice imperfections, x-ray and neutron diffraction structural studies, the nature of the strain hardened state, the mechanisms of recovery, recrystallization and grain growth in materials, and the physics of surface reactions.

Highlights of recent activities under the U. S. physical research program include such items as:

Publication by the White House of a report of a special panel on high energy physics of the President's Science Advisory Committee and the

Commission's General Advisory Committee, containing a proposed Federal program in support of high energy particle accelerator physics.

Completion and operation at the University of California Lawrence Radiation Laboratory of a liquid hydrogen bubble chamber of unprecedented size for use in high energy physics research with particle accelerators.

Announcement of the discovery at the Lawrence Radiation Laboratory of the xi-zero hyperon, a neutral particle of greater mass than the neutron, and the photographing at the same laboratory of the first complete reaction containing the neutral anti-lambda hyperon, including the particle initiating the event.

Ground-breaking and initiation of construction of a 12.5 Bev proton accelerator, the Zero Gradient Synchrotron (ZGS), at the Argonne National Laboratory, and completion of repairs and return to operation of the 3 Bev Cosmotron at the Brookhaven National Laboratory.

Initiation of a long-range transplutonium isotopes production program with the objective of producing research quantities of americium, curium, berkelium and californium.

Basic research by its very nature is <u>international in character</u>. Although the Commission's physical research program is purely domestic - the Commission has no contracts abroad for basic research in the physical sciences - the academic-scientific community is international. Scientific literature of whatever origin is published in most of the world's major languages, and is read by scientists all over the world. Basic scientific discoveries are

made by researchers of all nationalities. Such discoveries belong to the human race and are not the monopoly of any one nation. Personal contacts between scientists of all nations, in formal conferences or informal visits and discussions, provide for the necessary valuable cross-fertilization of ideas.

In a broad sense, it can be said that all development of research information, and all advances in practical applications of atomic energy to human problems, as achieved in the domestic atomic energy program, contribute to the international program. The domestic program, in turn, receives benefits from the increased volume and variety of research throughout the world.

Research in the atomic sciences conducted all over the world, covering fundamental investigations in the above areas, is continually making useful and important contributions to man's knowledge in nuclear science and technology. Today's great technological achievements are based on yesterday's basic discoveries. Tomorrow's advances in development and hardware will be based on today's accomplishments in basic research.

EXCERPT FROM LETTER REQUEST TO ATOMIC ENERGY COMMISSION

This will confirm our conversation on November 19 concerning the preparation of a Report on Status and Prospects of Fusion Power.

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TRANSMITTAL LETTER FROM ATOMIC ENERGY COMMISSION

* * * * * * *

* * * you requested a report on status and prospects of fusion power * * *

I am happy to enclose a report in two parts prepared by the Commission's Division of Research * * *

* * * * * * *

THE WORLD EFFORT ON CONTROLLED FUSION-POWER

Background Material for the McKinney Review of International Atomic Policies and Programs. A Draft Prepared by the Controlled Thermonuclear Branch, Division of Research, U. S. Atomic Energy Commission, February 5, 1960

INTRODUCTION

In recent times the exchange of information on controlled thermonuclear research between the U.S. and foreign countries has increased at a very rapid pace. In the autumn of 1956 complete exchange between the U.S.A. and the United Kingdom was effectively organized. Partial declassification by the two countries began in 1957 and continued in 1958. Declassification by the USA, the United Kingdom and the USSR occurred in September 1958. In the same month a strong effort to acquaint other countries with the work in the USA was made, by exhibiting full-scale experimental equipment, in operation, at the Second Geneva Conference.

Numerous developments testify to the natural growth of our interactions with scientists in other countries who work in this field. These will be briefly listed:

1. Under the Agreement for Cooperation Concerning Civil Uses with the British, there have been thirteen meetings, large or small, dealing with fusion-power research, in the two countries. This does not include multi-national meetings, or brief visits by individuals. Since early 1958, scientists have been exchanged between Harwell and American laboratories, for stays of roughly one year.

2. After the Geneva conference, the CERN Council authorized the formation of a Fusion-Study Group, at which scientists of the CERN countries could discuss the extensive material presented at Geneva and additional information about their national programs in this field. This group has held several meetings, and will continue to do so for a time. Representatives of Euratom and OEEC are included in the membership. Usually an American representative is invited.

3. An informal invitation for delegations from CERN countries to visit American laboratories was issued. Since the Geneva conference we have received four delegations, from France, Japan, the Netherlands and the USSR. Numerous individual visits have occurred in both directions.

4. As to visits of approximately one year, several Americans are in Western European thermonuclear laboratories, and scientists from other countries have been received at Princeton, New York University, and LRL, Berkeley. One-year postdoctoral research associateships at the Princeton project have been granted to three Europeans, an Asian and one American.

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5. The McCone-Emelyanov understanding may be expected to lead to an exchange of visits of controlled thermonuclear personnel of the USA and the USSR. The understanding also provides for exchange of documents, reports and abstracts on a reciprocal basis, and for initial exploration of the possibility of joint facilities and undertakings in controlled thermonuclear reactions. It is provided that the International Atomic Energy Agency and its interested members "will be given all reports and the results of the exchanges and, to the extent possible, the Agency will be asked to assist in the consideration of possible joint projects by sponsoring meetings, symposia or studies considered necessary for such planning."

GENERAL FACTS CONCERNING THE WORLD EFFORT

In this section we shall present facts of general nature before proceeding to brief remarks on the programs of individual countries. At present we have knowledge of appreciable research, or plans for such research, on controlled thermonuclear reactions in the following countries:

Australia	Netherlands
Belgium	Norway
Denmark	Poland
East Germany	Roumania
Finland	Sweden
France	Switzerland
German Federal Republic	United Kingdom
Israel	USA
Italy	USSR
Japan	

The description of the status in western Europe is based largely on a comprehensive report of the CERN Study Group on Fusion problems (4), which contains accounts of research and statistical data, collected in early 1959.

The programs in the United Kingdom, in the USA and the USSR each embrace several approaches to the problem of creating a thermonuclear plasma. In general, work in any other country is less diversified than that performed by the USA, the USSR and the UK, but between them, the other nations now have studies or experimental programs concerned with nearly all the principal methods employed in the UK, the US and the USSR. (An exception, for example, is work with relativistic electrons, — such as the Astron studies at Livermore.) Many of the programs in western Europe began with pinched discharges and related methods. (The pinch method employs condensers to supply transient power; thus it offers an expeditious way to obtain reasonably hot plasmas).

1. The Question of a Central European Laboratory

The CERN fusion study group considered whether there was a need for a European laboratory, in addition to those already existing, and came to the following conclusion:

"It was felt by the Study Group that unless it can be demonstrated that a European laboratory is needed in order to build larger facilities than can be built by national groups, the many other advantages of such a centre may prove insufficient to overcome the difficulties in its creation and maintenance."

It should be noted that in the USA the existing four major projects (at Los Alamos, Lawrence Radiation Laboratory, Oak Ridge and Princeton) arose largely from the existence of interested groups at laboratories already deeply involved in accelerator technology and discharge phenomena. By virtue of meeting the normal needs of these groups, the pattern had solidified by 1957. Long before that, a central Sherwood laboratory had been discussed but the idea was found to be almost unfeasible.

2. Training and Personnel Exchange

It appears that in both Europe and America there is no lack of suitable training opportunities on the phenomena of electrical discharges in gases. As for training in the specific problems of fusion, attention has been given to this in both continents. We have mentioned that Princeton at present has four postdoctoral research associates from abroad. There have been special courses at Saclay and Munich, and the Italian Physical Society arranged a summer school at Varenna in 1959.

It is estimated that approximately five American fusion scientists will be in European fusion laboratories and eight to ten foreign scientists will be in American fusion laboratories, during some substantial part of 1960.

(4)

3. The Part Played by Euratom

Aside from funds supplied by individual governments or industries for national programs, Euratom has several million dollars available for fusion research; furthermore, Euratom is supporting scholarships at Saclay and Munich in the field of controlled Thermonuclear reactions.

4. Recommendations of the CERN Fusion Study Group

The group recommended:

(1) Regular review of the European programs, including a second examination of the question of a European laboratory after a year.

(2) Regular discussion meetings of 60 people or less, to be held in rotation at the main European fusion laboratories. Such a meeting was held in Munich in November 1959.

(3) Arrangements for personnel exchanges.

(4) Special attention to training.

(5) Mechanisms for exchanging reports.

(6) Close collaboration with laboratories in the USA and the USSR.

There was also discussion of setting up a European Society for Controlled Thermonuclear Research.

5. Personnel and Costs

Table 1 gives the CERN estimates of fusion-power personnel and recent "operating costs" in western European countries, together with AEC figures. Informal estimates by American scientists indicate that in 1959 the total number of people involved was much the same for Europe and the UK together, the USA, and the USSR. Because of differences in accounting practice and definitions of scientific staff, comparisons of cost per man have little meaning. The American laboratories use technicians, general shops and subcontractors very heavily.

TABLE 1. Approximate Fusion Power Personnel and Operating Costs in Calendar 1959

Country	Scientific Staff	Operating Cost, Million Dollars
UK	150	6
France	60	2.5
Germany	110	2.0
Remainder of Europe	154	2.4
Total, UK and Europe	474	12.9
USA	347	38.0 *

* Includes large transient expenditures for Model C facilities at Princeton. For fiscal 1961, the President's budget submitted to Congress proposes $25 million for controlled thermonuclear research. This sum includes only about $2 million for completion of Model C.

6. Summary Table

Table 2 gives the locations at which work is or is expected to be performed in December 1959. In the case of the USA, we have listed all the smaller groups under contract to AEC. There are in addition many other American groups which work on plasma physics having at least some bearing on the controlled fusion problem.

TABLE 2. Known Locations of Controlled Thermonuclear Work

Country and Organization	Location
Australia	
University of Sydney	Sydney
Belgium	
Physics Institute, Universite Libre de Bruxelles	Brussels
Denmark	
Risö Research Center	Roskilde
Finland	
University of Helsinki	Helsinki
France	
Commissariat a l'Energie Atomique	CENFAR, Fontenay-aux-Roses CEN, Saclay, Paris
Laboratoire Central de l'Armament	Limeil, Brevannes
East Germany	
Physikalisch-Technisches Institut (d. Deutschen Akademi d. Wissenschaften)	Berlin
Research Institute for Ultramicroscopy and Physics of Charge Carriers	Dresden
Institute for Magnetohydrodynamics of the D.W.A.	Jena
German Federal Republic	
Max Planck Institut für Physik and Astrophysik	Munich
Laboratorium für Technische Physik der Technischen Hochschule	Munich (Garching site)
Physikalische Institut der Technischen Hochschule	Aachen
Forschungslaboratorium der Siemens-Schuchertwerke A.G.	Erlangen
Technische Hochschule	Hannover
University of Kiel Institute für Experimentalphysik	Kiel
Institut für theor. und angew. Physik der Technischen Hochschule	Stuttgart

Table 2 (continued)

Country and Organization	Location
Israel	
Israel Institute of Technology	Haifa
Italy	
Institute of Physics, University of Rome	Rome
CAMEN	Leghorn
Japan	
See Table 3	
Netherlands	
FOM Institute for Plasma Physics	Jutphaas
FOM Institute for Mass Spectrography	Amsterdam
Theoretical FOM Group, University of Delft	Delft
University of Utrecht	Utrecht
KEMA	Arnhem
Physical Laboratory of the Philips Works	Eindhoven
Norway	
Technical University	Trondheim
Poland	
Warsaw University	Warsaw
Sweden	
Royal Institute of Technology	Stockholm
Physics Institute, University of Uppsala	Uppsala
Chalmers University of Technology	Gothenburg
Switzerland	
Elektrotechnische Hochschule	Zürich
Brown Boveri Co., Ltd. and Reactor, Ltd.	Würenlingen

Table 2 (continued)

Country and Organization	Location
United Kingdom	
Atomic Energy Research Establishment (AERE)	Harwell, Berks.
Research Laboratory of Associated Electrical Industries, Ltd. (AEI)	Aldermaston Court, Berks.
Atomic Weapons Research Establishment (AWRE)	Aldermaston, Berks.
Imperial College	London
Sheffield University	Sheffield
University of Liverpool	Liverpool
United States of America	
Four Major Groups:	
Los Alamos Scientific Laboratory (LASL)	Los Alamos
Lawrence Radiation Laboratory (LRL)	Berkeley and Livermore
Oak Ridge National Laboratory (ORNL)	Oak Ridge
Princeton University	Forrestal Research Center, Princeton
Work in Collaboration with AEC at Other Government Agencies	
National Bureau of Standards	Washington, D.C. and Boulder
Naval Research Laboratory	Bellevue, Anacostia

Table 2 (continued)

Country and Organization	Location
Smaller Groups Under Contract to AEC, January 1960	
MIT, Research Laboratory of Electronics	Cambridge
New York University, Department of Physics	University Heights
New York University, Institute of Mathematical Sciences	Waverley Place
Stevens Institute of Technology, Department of Physics	Hoboken
University of Delaware, Department of Electrical Engineering	Dover
University of Tennessee, Department of Physics	Knoxville
Georgia Institute of Technology, Engineering Experiment Station	Atlanta
University of Miami, Department of Physics	Miami
Westinghouse Electric and Manufacturing Co., Research Laboratory	East Pittsburgh
University of Illinois, Dept. of Electrical Engineering	Urbana
Northwestern University, Department of Physics	Evanston
University of Chicago, Fermi Institute for Nuclear Research	Chicago
General Mills, Inc. (under contract to Metallurgy and Materials Branch, AEC)	Minneapolis
University of Houston, Department of Physics (under contract to Mettallurgy and Materials Branch, AEC)	Houston

Table 2 (continued)

Country and Organization	Location
P.E.C. Corporation	Boulder
Stanford University, Dept. of Physics	Stanford
Space Technology Laboratories	Los Angeles
Industrial Groups	
C-Stellarator Associates	Princeton
This corporation was formed by Allis-Chalmers Manufacturing Corporation and Radio Corporation of America to design, fabricate and install the Model C Stellarator. These two companies are under contract to Princeton University for this purpose.	
General Atomics Division of General Dynamics Corporation, in collaboration with Texas Atomic Energy Foundation.	La Jolla
General Electric Company, Research Laboratory	Schenectady
USSR	
Institute of Atomic Energy	Moscow
Ukrainian Physico-Technical Institute	Kharkov
Physico-Technical Institute	Leningrad
Institute for Electrophysical Apparatus	Leningrad
Institute of Electronic Physics	Sukhumi

PROGRAMS IN INDIVIDUAL COUNTRIES

Australia

A department for controlled thermonuclear research has been established in the University of Sydney. The first occupant of this chair will be Prof. C. N. Watson-Munro, recently Chief Scientist of the Australian Atomic Energy Commission, who is spending several months at the Lawrence Radiation Laboratory, Berkeley, before taking up his new duties.

Belgium

Theoretical work is done at the Institut de Physique, University of Brussels. A linear pinch system was under construction in 1959.

Denmark

The Physics Department at Risö Research Center has focused its attention on careful studies of thermalization, plasma losses and smaller topics. The group has used this information to consider the power balance in both steady state and transient reactors. Current planning calls for construction of an experiment on plasma acceleration using plane geometry, to be completed in 1960.

Finland

Calculations on radio frequency heating of low-density plasmas have been done at the University of Helsinki.

France

Work has been initiated in both Saclay and Fontenay-aux-Roses. The heavy experimental work will be concentrated at Fontenay-aux-Roses. Studies of pinch discharges have been the chief experimental item in recent years, but design of a high energy injection machine, somewhat similar to DCX, is in progress. The Saclay group is involved in a variety of small experiments on microwave diagnostics, radio frequency confinement and heating, shock heating, arcs, ion sources, and plasma betatrons.

The Laboratoire Central de l'Armament has devoted some attention to reaction rates, cooperative phenomena, thermalization and blanket problems.

East Germany

Several institutes affiliated with the German Academy of Science in Berlin are known to have small-scale efforts on relevant plasma physics.

German Federal Republic

The theoretical group at the Max Planck Institute in Munich has made outstanding contributions in the field of plasma physics, concerning itself broadly with problems of confinement, stability and heating. The growing experimental effort involves work with a large toroidal pinch, a small stellarator-type device, the development of a variety of diagnostic techniques, and vacuum problems. A smaller independent group at the Technishe Hochschule works in close collaboration with MPI on fast linear pinches and rapid compression devices.

The group at Aachen has concentrated on rapid shock compression devices, the development of fast condenser banks and switches, and diagnostic methods.

Spectroscopic methods for studying plasmas are pursued at Kiel.

Experimental pinch work is also being carried out by small groups at Hannover, Siemens and Stuttgart; the latter group has also published on fundamental theoretical studies.

Israel

Non-linear plasma oscillations have been studied at the Israel Institute of Technology.

Italy

A University of Rome group will perform experimental work at a nearby reactor site, Bracciano. Their planning calls for a mirror shock machine which can be considered a modification of Scylla.

At Camen, Leghorn, theoretical work has been done on a confinement system involving both magnetic and electric fields.

Japan

It is stated that controlled thermonuclear experimentation in Japan began with studies of linear condensed discharges at Osaka University, in early 1956. Later that year the Atomic Energy Commission of Japan arranged for correlation of the efforts of Japanese scientists. A nuclear Fusion Research Group chaired by Dr. Hideki Yukawa was organized. It was estimated in 1958 (6) that as many as 30 research groups were interested in this field. Table 3 lists experimental activities which have come to the attention of the USAEC. It is probably incomplete, but serves to indicate Japanese effort on a majority of the heating and confinement methods strongly pursued in European countries and the USA. (The exceptions noted, in the case of the USA, are the Astron, steady-state injection into mirrors, and the stellarator).

In August 1959, it was announced [7] that "Japan will carry out only fundamental researches of fusion reaction, mainly at university laboratories and various other independent research institutes, as before."

Table 3

Controlled Thermonuclear Research in Japan [7]

Organization	Nature of the Research
Kyoto University	Confinement by helical fields
Nagoya University	Toroid pinch
Nippon University	Transient mirror device, with plasma of relatively high density
Osaka University	Linear pinch
Tohoku University	Magneto-hydrodynamic wave resonance
Tokyo University	Plasma betatron
Tokyo Engineering University	Straight pinch
Electrotechnical Research Laboratory (Ministry of International Trade and Industry)	Shock-mirror device and toroid pinch
Central Research Institute, Hitachi, Ltd.	Plasma heating by sonic waves, and by cyclotron resonance
Tsurimi Laboratory, Tokyo Shibaura Electric Industry Co.	Pinch research

Netherlands

The Dutch groups listed in Table 2 work in close cooperation. Funds are provided by the Foundation for Fundamental Studies of Matter, — Stichting FOM.

Certain funds are obtained directly from FOM and others are channelled into the laboratories through the state-supported universities. The chief experimental locations are the Institute for Plasma Physics at Jutphaas, near Utrecht, and the Institute for Mass Spectrography at Amsterdam. There is collaboration with KEMA, a utilities company and with the Phillips Laboratory.

In addition to theoretical work there are plans for a device using crossed electric and magnetic fields. The use of protons and heavy ions for probing plasmas will also be explored, and there may be some work on cusped geometry and ion cyclotron heating.

Norway

A small group has been formed to study plasma physics problems.

Poland

At Warsaw University work has been done on critical masses for the development of fusion chain reactions.

Roumania

At the Institute of Atomic Physics, Bucharest, there is work on oscillations in a plasma exposed to an external magnetic field.

Sweden

Alfen's group in Stockholm arose from his work on astrophysical problems involving electromagnetic fields. An over-simplified statement is that the work has included a broad cross section of theoretical and experimental studies of the interactions between electromagnetic waves and particles in a plasma. Siegbahn's group at Uppsala works on both toroidal and linear pinches. Both groups receive aid from both the Swedish State Power Board and the Industrial firm ASEA.

Theoretical work is done at Chalmers University of Technology.

Switzerland

We are informed the Swiss government plans to support plasma studies by personnel of the Elektrotechnische Hochschule at Zürich on a scale of $250,000 a year.

Brown Boveri Co., Ltd. and Reactor, Ltd. have published on blanket problems.

CERN has supported plasma research connected with advanced accelerator concepts, but states that it is not entering the controlled thermonuclear field.

(5)

United Kingdom

Work at AERE, Harwell was concentrated on relatively slow toroidal pinches until very recent times. Associated Electrical Industries, in collaboration with Harwell, has worked along similar lines for several years. Work with straight tubes, and with toruses of about 12" minor diameter led to the construction at Harwell of the very large machine called Zeta, which was built by Metropolitan-Vickers and came into operation in mid-1957. At first it was thought that a stable plasma had been confined for several milliseconds, but this was found to be incorrect in early 1958.

Accordingly, the Harwell group moved to consideration of a modified program called ICSE, Intermediate Confinement and Stability Experiment. The intent is to utilize very dense plasma in a large torus of about 1 meter minor diameter, with more rapid current build-up than in Zeta.. Zeta is now being used to learn more about plasma behavior, providing also information of special interest for the ICSE development. The condenser power available has been increased. The ICSE experiment is expected to need a fast bank of 14 megajoules, but 7 megajoules will be provided initially to guide final development of the facility.

At the Atomic Weapons Research Establishment, the first work was focused on small pinches and shock compression devices operating on a microsecond time scale. More recently, mirror principles have come under study at both AWRE and AERE, and at the former, work has begun on an injection mirror machine called Phoenix.

Imperial College works on linear pinch and shock waves, Sheffield University on microwave techniques and the University of Liverpool on switching problems.

In general, the British work has been characterized by heavy attention to diagnostic methods and techniques, using a variety of small experimental devices. The British groups have made a great contribution in this area.

A decision has been taken to move all British controlled thermonuclear work, aside from small university efforts, to a new laboratory to be built at Culham, near Harwell. Buildings are expected to cost perhaps 3.5 million pounds and operating support may be at the rate of 2 million pounds per year.

USA

The comprehensive USA effort is well described in references 1, 2 and 3.

USSR (8)

The interest of the USSR in controlled thermonuclear research is attested by statements before the Twenty-first Congress of the Communist Party, meeting from November 1958 to February 1959. Its high priority was noted in speeches by Premier Krushchev and Academicians Nesmeyanov and Lavrentiev.

The largest group, in Moscow, at the Institute of Atomic Energy, is highly diversified. The group does theoretical work, plasma acceleration experiments, and a variety of experiments on pinch and related methods. The large mirror machine, Ogra, is located at this Institute.

The Physico-technical Institute and the Institute for Electro-Physical Apparatus at Leningrad make use of the large pinch device Alpha, which is similar to the British Zeta. It is located at the latter institute, which also built the Ogra machine.

The group at the Ukrainian Physico-Technical Institute is strong in theory but also does experimental work on plasma resonance and waveguide properties of plasma.

The Institute of Electronic Physics, at Sukhumi, has personnel well versed in ion source technology. There is also work on plasma oscillations.

FUTURE EXPECTATIONS

In these paragraphs we call attention to some possible developments which have been informally discussed at the Uppsala Conference, and elsewhere.

1. The IAEA has authorized establishment of an international quarterly devoted to controlled thermonuclear research. Member nations are being actively consulted on plans for this journal. Exchange of information, both informal and by publication, evidently is not a major problem.

2. It is hoped in many quarters that IAEA will take the lead in organizing a series of annual or biennial international meetings on fusion research. It has been suggested that the first meeting should be held in Vienna in the Spring of 1961.

3. The formation of the Division of Plasma Physics of the American Physical Society has removed the necessity for large AEC-sponsored meetings on fusion power in the United States. However, from time to time, it may be convenient for AEC to organize meetings for special purposes, such as clear and timely presentation of some particularly interesting advance.

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PROGRESS TOWARD FUSION POWER
THE U. S. PROGRAM*

During the last four years the progress in Project Sherwood, -- the U. S. research effort in the field of controlled fusion-power, -- has been steady, and the total advance is impressive. Highlights of recent progress in this field include the following:

1. In early 1956 it was not possible to say with certainty that any of the four major U.S. Sherwood laboratories had produced a plasma with the modest ionic energy of 100 electron volts, (EV). Now this energy has been pushed up more than ten-fold, -- beyond 1,000 EV, -- in the case of relatively dense plasmas containing more than 10^{16} ions per cubic centimeter. Further increase, by a factor of about five, would bring us beyond the ignition energy for the reaction between deuterium and tritium, described below.

2. Injection of very dense plasmas at an energy of a few hundred EV has become possible in very recent months. The significance and ramifications of this are being studied.

3. Hydromagnetically stable configurations of plasma and magnetic fields have been demonstrated by a method called "hard core pinch".

4. Methods for injecting very energetic ions (600 KEV) on a steady state basis have been developed, providing trapped ions with energies

* For a more detailed account of progress in the controlled fusion field, see Amasa S. Bishop, "Project Sherwood", 216 pp., Addison-Wesley, Reading, Mass., 1958; or the Doubleday edition, 1960, which includes an appendix on progress up to about June 1959.

well above the range needed for effective thermonuclear reaction, albeit at very low densities. The output of compact ion sources convenient for such high-energy injection has been greatly improved.

5. Large hollow arcs have been demonstrated as a means for keeping slow molecules from the walls out of the central region of a magnetic bottle.

6. In a mirror machine called "Table Top", a plasma with a significant ratio of particle pressure and pressure of the magnetic field has been confined for a period about 100,000 times longer than the time predicted for development of hydromagnetic instabilities.

7. Plasma jets can now be injected into transient mirrors, across the magnetic field, at energies of 500 EV or better, compared with 50 EV a year ago. The trapping of ions with large transverse energies, by collision of two or more such jets has been demonstrated.

8. Work on injection and trapping of high-energy neutral atoms is under way.

9. The capability for handling large currents of relativistic electrons is advancing rapidly; 600 KEV electrons have now been confined (in a sufficiently high vacuum) for times of the order of one second.

10. The method called "ion-cyclotron-resonance heating" has been greatly developed. By this method radio-frequency power has been introduced into a plasma with an efficiency greater than 75 percent.

11. Stellarator performance has been enhanced by improvement of vacuum, use of rapid pulsing, and use of suitably purified hydrogen, -- among other measures. The Model C stellarator is expected to be complete in the spring of 1961, making possible definitive studies of a variety of methods for heating a plasma confined in a helical field.

The nature of this effort to release the energy of hydrogen isotopes in a controlled reaction must be clearly stated. In the early days of the development of fission power, there were many over-optimistic statements about the date of its general availability at competitive prices. It must be emphasized that current efforts in the Sherwood field are devoted to the creation of a thermonuclear plasma, so that the possibility or the impossibility of fusion machines producing net power may be determined.

The successive steps in controlled thermonuclear research are as follows:

1. To heat and confine a plasma at a particle-energy equal or superior to the so-called ignition energy. (By definition, at this energy level, the kinetic energy added by the fast-moving products of thermonuclear reactions would be just sufficient to overcome the loss of X-ray energy by the hot plasma.) For the DT reaction, -- the reaction of deuterium and tritium, -- the ignition energy is about 6,000 EV, while for the DD reaction, -- that of two deuterons, -- the value is much higher, about 53,000 volts.)

2. To study such thermonuclear plasma, and, if it be thought possible to design and build a pilot plant yielding net power.

3. To assess, by experience, the possibility of economic generation of power.

That these goals are substantially successive is readily apparent. The dominant feature of current fusion-power research is a continuing fight against unstable motions of the hot gas. Especially during the heating process, some of the hot gas is carried to the walls of the confinement vessel, in spite of the strong magnetic fields employed to keep the gas confined. It has long been understood that the margin between success and failure is measured by a small integer, basically dependent on the confinement time. This number cannot be calculated in detail, but is probably not in excess of ten in the most favorable case. The present research is concentrated on the first goal, -- to heat plasma above the ignition energy. The road is a devious one, involving experiments large and small, and laborious calculations. In each of the present lines of major effort, there is no doubt that further substantial advances can be made. There is general confidence among U.S. scientists that the ignition energy can be reached and exceeded. Statements concerning the probability of attaining net power production, or concerning the production of economical power, lie beyond the limits of present knowledge.

It is not likely that there will be any sudden breakthrough. While it is hoped that the ignition energy may be reached in a relatively short time, perhaps one or two years, such hopes had been entertained earlier, only to be dashed by the appearance of technical difficulties that came to light only when some of the more obvious ones had been overcome. Therefore, it is safer to say that the time for attainment of Goal 1 may be five years.

When and if the ignited plasma is attained, the emphasis should quickly shift to improvement of the time of confinement of a typical ion, and to engineering and chemical studies (such as intensive work on wall materials, shielding, and magnetic coil design.) This work will be preceded by a thorough-going feasibility study which could be expected to overlap the five-year period.

Until the early months of 1959, it was thought that thermonuclear reactors would necessarily be of very great size, a single plant being suitable only for a large power consuming area. It was known that some reduction of size might be attained by economics in magnet power, -- to be achieved by cooling the confining-field coils to temperatures in the liquid hydrogen range. Renewed studies of cryogenic coils indicate that by using them to provide steady state magnetic mirrors, the minimum internal power consumption of a working power plant could possibly be brought down to a value of the order of 10 megawatts, and useful power of the same order of magnitude could be produced.

The position, therefore, is that if proper stability of the confined plasma can be achieved, the task of working toward a pilot plant will probably be easier than anyone would have supposed, prior to 1959.

Advantages and Limitations of Fusion Power

The advantages of fusion power, relative to conventional and fission power, have often been stated as follows:

1. Cost of the basic fuel deuterium, is negligible. It would be unnecessary to reprocess unburned deuterium for its own value.

2. This fuel is essentially inexhaustible.

3. The waste-disposal problem is avoided. While parts of the fusion machine will be activated by fast neutrons, the metals and ceramics which become radioactive can be chosen so that maintenance problems are greatly reduced. Risks to the general population would be absent and negligible.

4. A fusion plant cannot run away. The explosion risks are only those of any steam power plant.

5. A portion of the electricity can be generated directly by expanding the hot plasma, without intervening thermal cycles and moving parts.

It is actually difficult to point out any substantial disadvantage of fusion power, provided that it turns out to be competitive costwise. However, some of the advantages mentioned require comment and emendation.

As to cost and reprocessing of the fuel, it must be noted that the DT reaction has a cross section about one hundred times larger than that for the DD reaction. It is expected that the first generation of fusion reactors would be DT reactors. There is even now a certain body of scientific opinion that DD reactors will never be feasible, mainly because of the smaller cross-section. If so, neutrons from the DT reaction will have to be used in a blanket containing a lithium compound to regenerate tritium. Since some neutrons will be lost, a means for multiplying them is needed, so that tritium can be bred in excess of that used in the reactor. This can be done by making judicious use of the (n, 2n) reaction of beryllium or other suitable elements. The problem of recovering a low concentration of tritium from the blanket will require considerable research.

The possibility of hybrid reactors, making use of both fusion and fission, has been considered. Natural uranium (or thorium) in the blanket could be used to produce plutonium (or U-233), and also to increase the breeding of tritium. (This approach, of course, would re-introduce the problem of fission products). Fusion reactors and breeding fission reactors are the extreme members of a whole series of hybrid reactors. From this point of view, the efforts on Sherwood and on fission breeders should be considered complementary, rather than competitive.

As to inexhaustibility of the fuel, it has been known for some time that the uranium and thorium of ordinary rocks are in principle sufficient, -- being of the order of a few parts per million, -- to supply our power needs for the indefinite future, provided that suitable means of recovery are devised and that breeder reactors are sufficiently successful. Thus fusion and fission power may stand on a common footing as regards the total abundance of the basic fuel materials.

As to direct generation of electricity, the fraction of the nuclear power release which might be so extracted is small in the case of the DT reaction, since the neutrons escaping to the blanket carry away 80% of the reaction energy. This part appears as heat, along with an increment from the final reaction of these neutrons with the blanket material.

Dr. Edward Teller, on the matter of advantages and disadvantages of fusion power has stated as follows:

"It is my opinion that present estimates of advantages and

disadvantages of a fusion reactor are likely to miss the really practical point. Technical predictions about the distant future are necessarily unreliable. The main argument for developing controlled fusion energy producers is, in my opinion, the following:

> Controlled fusion is so different from other energy sources that in case of its feasibility, it will turn out to be advantageous, probably even more advantageous, in some situations. I expect that this unknown advantage will be great and I also believe that at present there is not much point in worrying about it."

It is believed that questions of the feasibility of long-range (or "ultimate") power sources will be cleared up by the present generation. Fossil fuel is not replaceable. Easy availability of fission and fusion power would encourage more effective use of carbon as a source of highly valuable materials. The sooner the facts about effective utilization of other fuels are known, the sooner the proper national and international positions on the best use of the remaining stocks of coal and oil can be established.

LETTER REQUEST TO THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

In view of the growing interests by the world's scientific community in the future application of controlled fusion to power, propulsion and other purposes, I have included it in the review of U.S. international atomic policies and programs, which I am conducting on behalf of the Joint Committee on Atomic Energy. Research on controlled fusion which is being undertaken or planned by CERN may be expected to play an important role in any successful development of fusion energy for peaceful purposes. I should therefore appreciate your assistance in obtaining any current information which may reflect the following:

1. Present research programs of CERN which may be applicable to the control of thermonuclear reaction.

2. Future plans for research and development work by CERN; information on the approaches to be utilized, equipment to be constructed or purchased would be most helpful.

3. Present and future plans for cooperation with other nations or international organizations in research and development work on controlled fusion.

4. An appraisal of (a) the stages of research and development work remaining; (b) a range of time when controlled thermonuclear energy might be achieved, i.e. the energy output of the machine would be greater than its energy input; and (c) a range of time estimate when fusion energy might be utilized economically on a commercial scale.

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LETTER FROM CERN

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Thank you very much for your letter of 8 March which I read with great interest.

To answer the first question in your letter, I should like to explain that thermonuclear research has never been one of the main objectives of CERN as this particular branch of research did not fall strictly within the provisions of the Convention establishing the Organization.

Since the middle of 1958, however, CERN has been sponsoring a Study Group on Fusion Problems which was set up to prepare a research programme on plasma physics. All European experts in the field have taken part in the work of this Study Group which met several times in the course of 1958–1959.

In June, 1959, a first report was presented to the CERN Council, putting forward the recommendations and proposals of the Study Group as to their future activity.

Enclosed is a copy of this report which I hope may be of some help to you in the study you are undertaking on behalf of the Joint Committee on Atomic Energy and should answer the other questions raised in your letter.

I should like to add that, at its Fourteenth Session, on 2 December, 1959, the Council of CERN decided, on the basis of a second report, copy of which is also enclosed, that the Organization should continue to sponsor the Study Group until the end of 1960, when the question will be reconsidered.

CERN/304

EUROPEAN FUSION RESEARCH

REPORT OF THE CERN STUDY GROUP ON FUSION PROBLEMS

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Part I - General

1. Reasons for setting up the CERN Study Group on Fusion Problems

In March 1958 a number of scientists met at CERN for a few days to talk about the results of plasma physics experiments aimed at controlled thermonuclear reactions being undertaken in various laboratories. At that time the most notable results were from the Zeta machine at AERE, Harwell and consequently most of the discussion was centred about these results. It became clear during the discussions that there were many European laboratories engaged in this type of work and many others seriously thinking of entering the field. Due to security classification, very little of the work done on fusion had been published at this time and many laboratories found themselves in the awkward situation of planning research which they feared might have been already completed elsewhere. The partial lifting of the security restrictions at the beginning of 1958 was the main reason for these first discussions at CERN. It was hoped that very much more information would be released at the 1958 Atoms for Peace Conference in Geneva and that it would then be possible to form a comprehensive picture of the real state of fusion research in the world.

As a result of these first talks at CERN in March 1958 and the steady release of information on fusion work in the following months, CERN was asked by many laboratories to extend the original discussion group into a more formal study group and to arrange a series of meetings during the remainder of 1958.

At the June 1958 session of the CERN Council, approval was given to form a CERN Study Group on Fusion Problems and to hold the meetings at CERN in Geneva.

2. Objectives of the Study Group

The CERN Council, in giving its approval to the formation of the Study Group, agreed that the main objectives would be to exchange information on fusion research, to discuss the programmes being undertaken in the various laboratories and to consider ways of facilitating fusion research work in Europe.

The final report of the Study Group to the CERN Council would be issued as a CERN report with the normal circulation and be freely available.

3. Participants of the Study Group

Each European laboratory working in the field of fusion research was asked to send along a few representatives to the Study Group meetings. In addition to CERN, Euratom and OEEC were asked to participate as international organizations. Also the AEC was invited to send its European representative, Dr. Amasa S. Bishop, to the meetings.

The list of participants was as follows:

BELGIUM

Prof. P. Baudoux
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Risö
Roskilde
(attended 1st meeting)

Dr. T. Hesselberg Jensen
Risö Research Center
Physics Department
Risö
Roskilde
(attended 3rd meeting)

Dr. Carl F. Wandel
Risö Research Center
Physics Department
Risö
Roskilde
(attended 2nd meeting)

FRANCE

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Dr. S. Lundquist
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Dr. N. R. Nilsson
Fysiska Institutionen
Uppsala
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Prof. K. Siegbahn
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Mr. J. B. Adams (Chairman)
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Dr. J. G. Linhart
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(attended 1st, 2nd, 3rd meetings)

Dr. G. L. Munday
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Dr. E. Regenstreif
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Dr. A. Schoch
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(attended 1st, 2nd, 3rd meetings)

4. Brief review of the activities of the Study Group

The first meeting of the Study Group took place on 25th and 26th September 1958, shortly after the 1958 Atoms for Peace Conference in Geneva.

In the months previous to this meeting a great number of reports had become available to the members of the Study Group from the laboratories participating in the Atoms for Peace Conference. Also nearly all the members of the Study Group had taken part themselves in the Conference and had many discussions with colleagues abroad already working in this field of research for many years.

The first meeting of the Study Group was therefore devoted to trying to assimilate the information released at the Atoms for Peace Conference. Four half-day sessions were arranged as follows:

1. Stellarator Devices
   (session led by Dr. A. Schlüter - Göttingen and Munich)
2. Toroidal Pinch Devices.
   (session led by Dr. R.J. Bickerton - AERE, Harwell)
3. Linear Devices
   (session led by Prof. K. Siegbahn - Uppsala)
4. Mirror Devices and Centrifugal Devices.
   (session led by Dr. J. G. Linhart - CERN)

Each of these discussion sessions opened with a review of the device, its state of development, results of experiments and the difficulties encountered, both theoretical and experimental. During the discussions members of the Study Group outlined their own programmes of research work.

It became clear during the meeting that too little time had elapsed since the general release of information on fusion research for any serious evaluation of the state of the work to be made at the first meeting. It was therefore agreed that members of the Study Group would undertake to write critical surveys of the various devices and lines of approach to the fusion problem and circulate these reports in time for a second meeting.

The minutes of the first meeting were circulated to all the members together with a technical summary of the discussions that took place.

The second meeting of the Study Group took place on 11th and 12th December 1958. Nearly all the reports promised by the members of the Study Group were available at the second meeting. The full list of these reports is as follows:

1. Remarks on the Stellarator Scheme, by members of the M.P.I., Munich.
2. Brief Review of the Toroidal Stabilised Pinch, by R. J. Bickerton, Harwell.
3. Report on Linear Pinch Devices, by R. Latham and J. A. Nation, Imperial College.
4. Les machines à miroirs magnétiques, par M. Bineau, T. Consoli, F. Prévôt, P. Ricateau, C.E.A.
5. Les machines à miroirs magnétiques, Résumé et esquisse d'un programme de recherches, par M. Bineau, T. Consoli, P. Hubert, F. Prévôt, P. Ricateau, A. Samain, C.E.A.
6. La machine d'Osovetz, par Ch. Maisonnier, C.E.A.
7. Notes on fast Magnetic Compression of Plasmas, by H. L. Jordan, H. Kever and K. Schindler, Technical University, Aachen.
8. Confinement and Heating of Plasma by R.F. Electromagnetic Fields, by C. M. Braams and J. C. Terlouw, F.O.M. Instituut voor Plasma-Fysica, Rijnhuizen-Jutphaas.
9. Relativistic Electron Beam Devices for Fusion, by J. G. Linhart and A. Schoch, CERN.
10. Notes on some Theoretical Investigations of the Physics of High Temperature Plasmas, by Dr. Lüst, Munich.
11. A Compilation of Cross Sections and Rates of Interest in Controlled Thermo-nuclear Research, by the Risö Study Group.
12. The Betatron Method of Heating a Plasma to High Temperatures, by G. I. Budker, translated from Russian.
13. The Instability of a Plasma in a Magnetic Field in the Presence of Ionic Beams, by Kadomtsev, translated from Russian.
14. The Physics of Plasmas, U.S.S.R. Academy of Sciences. Abstracts of 4 volumes, translated from Russian.
15. Plasma Diagnostics by Spectroscopical Means, by H. Wulff, M.P.I.
16. Detection of Heavy Particles in Thermo-Nuclear Reaction Experiments, by L.H.Th. Rietjens and C.M. Braams, F.O.M. Instituut voor Plasma-Fysica.
17. High Speed Photography, by A. Folkierski, Imperial College.
18. Les sources d'ions et de plasma, par T. Consoli, P. Hubert, R. Le Quinio, D. Véron, C.E.A.

19. Short Note on Energy Storage, by D.Th.J. ter Horst, KEMA.
20. Ultra High Vacuum Technology, by G.L. Munday, CERN.
21. High Magnetic Fields, by S. Berglund, Uppsala Institute of Physics.
22. Investigation in Magneto-Hydrodynamics and Plasma Physics of Interest to the Thermo-Nuclear Problems, by H. Alfvén, Technical University, Stockholm.

On the first day of the second meeting a discussion took place on the above reports when the authors had the opportunity to give a brief review.

The Study Group, having by this time more or less assimilated the vast amount of published literature in the field of fusion research and having reviewed, in the light of this knowledge, their own fusion programmes, were able on the second day of this meeting to begin to discuss the general problem of fusion work in Europe.

A record was made on the plans and programmes of the European laboratories working on fusion problems and allied fields of research together with the effort in terms of staff and money that each laboratory intended to put into the work. A comparison was then made with the work being undertaken in the USA and the USSR. The question of an international European laboratory for fusion problems was discussed. Education, staff training and exchange of information in various forms was also considered.

At the end of the second meeting it was agreed that the Chairman should prepare a report summarizing the views expressed by the members of the Study Group and that this report, which would be considered as the first draft of the final Study Group report, should be circulated before the third meeting and form the basis of the discussions at the third and final meeting of the Study Group.

The third meeting of the Study Group took place in Geneva on 5th and 6th March 1959. Most of the first day was spent in a detailed discussion of the Draft Report of the Study Group to which many corrections, additions and changes of emphasis were suggested. The later part of the first day and the whole of the second day were devoted to status reports from the members of the group. Dr. Colgate from the Livermore Laboratories of the University of California,

Berkeley who attended the second day sessions gave a review of the work of his group, which includes sodium model experiments to investigate the hydromagnetic instabilities in pinch geometries, an electron beam experiment for analyzing the co-operative phenomena associated with runaway electrons and a Hard Core (or unpinch) experiment. The contributions of the members of the Study Group are reported at length in the Minutes of the third meeting.

Part II. Review of the activities of European laboratories working on fusion problems

A record was made by the Study Group of the plans and programmes of European laboratories working on fusion problems. It must be made quite clear that this record does not bind the laboratories to the plans announced below in any way. The object in making the record was simply to see how the various programmes interlocked together as far as they could be determined at the present time.

a) BRITAIN

The largest laboratory working on fusion problems in Britain is at AERE, Harwell (CTR Division). In addition to this major effort there are smaller groups at AWRE, Aldermaston, an industrial group at AEI, Aldermaston and several university laboratories.

i) AERE, Harwell (Dr. P.C. Thonemann, Dr. R. S. Pease, Dr. R.J. Bickerton)

Their programme is centred around the toroidal pinch system and the largest device is the machine called Zeta. Many modifications have been made to the original Zeta and will be made in the future, but for some time to come this machine will be the largest single device in the programme. Many smaller toroidal devices have been made and many more are in course of construction, all of them designed to answer specific problems concerned with the toroidal pinch geometry. In this general programme linear pinch systems are also being investigated in so far as they lead to an understanding of the pinch phenomena. A full range of diagnostic devices have been built and are constantly being added to as the need arises and development is possible. There are plans to increase the

energy storage facilities of the laboratory, firstly in order to extend the use of Zeta as an experimental tool and secondly to have available in four or five years' time a large energy storage facility for general use with magnetically confined plasma. This new power facility will be in three sections, namely a condenser bank store of about 25 M joules for "fast" experiments, an inductive energy store of about 200 M joules and a store using batteries or rotating machinery of about 1000 M joules. Such a power facility, which is about the same size as that planned for the Stellarator C device at Princeton, will take a great deal of development effort and time and will cost about 20 M $. It is the largest power facility planned as yet in Europe.

ii) AWRE, Aldermaston (Dr. S. C. Curran)

This group has contributed to the linear pinch devices and particularly to the technology of fast switching of condenser banks. This work continues, but in parallel work on a device labelled Thetatron is being prosecuted. Relatively small systems, straight and toroidal, are employed. Heating and stability are both studied and crowbar techniques are involved. X-rays and neutrons are examined. Work has begun on Hitex, which is similar in principle to the DCX machine at Oak Ridge. It is not intended that this device should represent a large investment - it is an effort to examine the principles as economically as possible in terms of equipment and it may be tackled at say about 50 kV rather than at say 500-800 kV. Most of the work would be on hydrogen rather than deuterium.

iii) AEI, Aldermaston

This is an industrial group working on the toroidal pinch device called Sceptre, in collaboration with AERE, Harwell. In a sense their work is complementary to that at Harwell and might be considered as part of the Harwell pinch programme. A new device, called Sceptre IV, using a 1 M joule condenser bank and a torus 30 cm bore, 1 m diameter is being built to study slow discharges up to 300 K amperes.

iv) University Laboratories (Dr. R. Latham - UCL)

Several university laboratories are engaged in work on specific aspects of fusion problems, notably Imperial College, London, which is concerned with linear pinch systems using fast photography and also shock wave systems, Sheffield University which is undertaking development of microwave diagnostic techniques, and Liverpool University where some work is in progress on condenser bank switching.

It is hoped to get more universities in Britain interested in plasma physics work, both theoretically and experimentally.

b) GERMANY

The Max-Planck-Institute for Physics and Astrophysics in Munich, formerly in Göttingen, has added to the original theoretical group an expanding experimental group. Also in Munich there is a group at the Technical University engaged in fusion problems, which co-operates closely with the Max-Planck-Institute. At Aachen a group at the University is already working on fusion problems, and several other universities are also interested in specific aspects.

i) Max-Planck-Institute for Physics and Astrophysics, Munich (Prof. W. Heisenberg, Dr. G. v. Gierke, Prof. L. Biermann, Prof. A. Schlüter)

The theoretical work, started in 1956 and based on the earlier studies of astrophysical applications of plasma physics and magnetohydrodynamics, is concerned with the general problems of confinement, stability and heating of plasma and with a number of special problems arising from experimental work.

The experimental work is mainly with devices using toroidal field geometries, particularly those using external magnetic fields, such as Stellarators with helical windings.

The necessary diagnostic techniques, such as spectroscopy, microwave measurements and probes, are being developed with special emphasis on the basic physics aspects. At the present time only experiments on the scale of Stellarator B and Sceptre are being prepared.

A group under Dr. E. Fünfer at the Technical Physics laboratory (Director Prof. Maier-Leibnitz) is working in close collaboration with the Max-Planck-Institute on linear discharges and other fast systems.

Prof. A. Schlüter holds a chair of Theoretical Physics at the Munich University and devotes part of his teaching to plasma physics.

A site has been reserved and plans are being contemplated for a larger laboratory than the present Max-Planck-Institute which will ensure that future developments including larger power facilities will be available in due course.

ii) Physical Institute, Technical University, Aachen (Prof. W. Fucks, Dr. H. L. Jordan)

The programme is mainly concerned with "fast" devices, including shock tubes and involving fast condenser banks with the appropriate diagnostic techniques. Some work on relativistic electrons in plasma is contemplated.

iii) Other University Laboratories

Apart from the two main groups mentioned above, several university laboratories are engaged in fusion work, notably Kiel University where particular attention is given to the spectroscopic aspects.

c) FRANCE

Two groups, both of the CEA, are engaged in fusion work in France. Apart from these groups, small university laboratories and industrial groups are contracted by CEA for specific problems.

i) CENFAR, Fontenay-aux-Roses, Paris (Dr. G. Vendryes, Dr. P. Hubert, Dr. F. Prévôt)

This group has been engaged in fusion work for some time, mainly on a pinch programme. No very large projects in the toroidal pinch programme are planned, but rather a series of devices of about 1-2 m diameter aimed at obtaining basic physical understanding. In addition to this work a new programme on mirror devices is planned using various injection systems.

The group has developed a range of diagnostic techniques in the course of its work, including microwave measurements in the 8 mm band. New laboratories for this group will be ready in about one year's time. No decision has yet been taken on the power facility for this new laboratory, but a 1 M joule bank of condensers and possibly a 1 MW D.C. generator will be installed.

ii) Accelerator Division, CEA, Saclay, Paris (Dr. S. D. Winter, Dr. J. Taillet)

This group, which has recently built the Saclay 3 GeV synchrotron, is now turning to fusion work. Their plans are centred around mirror machines of the injection type similar to the DCX. They are in course of building up the necessary diagnostic techniques, including microwave measurement apparatus in the 4 mm band, and the appropriate technology. They also contemplate setting up an R.F. confinement system in order to have a quiescent plasma for study purposes.

d) HOLLAND, FOM (Prof. H. Brinkman, Dr. C.M. Braams)

The Dutch work on fusion is carried out in five groups covering the following topics: theory (Prof. H.C. Brinkman, TNO, Delft), diagnostic techniques and ion cyclotron resonance heating (Prof. J.A. Smit, University, Utrecht), ion magnetron (Prof. J. Kistemaker, FOM, Amsterdam), power facilities and linear pinch (Dr. D.Th.J. ter Horst, KEMA, Arnhem), and a central institute with a programme including general plasma physics, toroidal pinches and R.F. confinement (Dr. C.M. Braams, FOM, Jutphaas). The fusion work is in the general programme of scientific research of the foundation FOM and includes the assistance of KEMA, TNO, Philips, and University laboratories.

e) SWEDEN

i) Stockholm, Technical University (Prof. H. Alfvén, Dr. A. Dattner)

The group of Prof. Alfvén, which has studied problems in plasma physics for many years, is continuing its researches along some lines that may be of interest to fusion. The programme includes studies of magnetized rapidly moving plasma rings, instabilities in linear gas discharges and electron beams in longitudinal magnetic fields. Theoretical and experimental

studies of the propagation of electromagnetic waves in plasma are being carried out together with investigations of the interactions between waves and fast electrons in plasma. Dr. Lehnert has started the construction of a machine for confining plasma at 30 million degrees using the magnetic field from a circular loop. Development and studies of diagnostic techniques are carried on along with the different experiments. A condenser bank of 50 kW is under construction.

ii) Uppsala, Physics Institute (Prof. K. Siegbahn, Mr. L. Högberg, Dr. N. R. Nilsson)

The programme includes work on toroidal discharges and linear pinches.

Both these Swedish groups are helped by the Swedish State Power Board and the industrial firm of ASEA.

f) ITALY, Laboratorio Gas Ionizzati, C.N.R.N., Institute of Physics, Rome University (Prof. E. Persico, Dr. B. Brunelli)

This group has only recently been formed and will shortly move to the Italian reactor site of Bracciano, north of Rome. The programme is based on the mirror geometry. A machine of a modified Scylla type will be built for experimental work on fast compression heating.

g) SWITZERLAND, ETH, Zürich (Dr. H. E. Knoepfel)

No group yet exists, but there are plans to form a plasma study group as part of the ETH at the Swiss reactor site near Zürich.

h) NORWAY, Technical University, Trondheim (Prof. K. Johnsen)

A small group is being formed to study some plasma physics problems.

i) BELGIUM, Physics Institute, Free University, Brussels (Prof. P. Baudoux, Dr. Ch. Lafleur)

A small group is building a linear pinch system for studies of diagnostic techniques and is interested in related theoretical problems. This work is now a part of the general programme of researches of the I.I.Sc.N. (Institut Interuniversitaire des Sciences Nucléaires).

j) DENMARK, Risö Research Center, Physics Department (Dr. O. Kofoed-Hansen, Dr. C. Wandel)

A small group has been formed for fusion studies.

k) CERN, Geneva (Dr. A. Schoch, Dr. J. G. Linhart, Dr. G. L. Munday)

CERN is not engaged in fusion studies. A small group in the PS Division of CERN is however studying the problem of relativistic electrons moving in plasma, both experimentally and theoretically. This work is part of the accelerator research of CERN and is incidentally relevant to problems of the fusion device known as Astron. Studies in ultra high vacuum technology in relation to systems of a volume of several cubic metres are now being undertaken.

Part III. Discussions

1. On the nature of the fusion problems in the next few years

In the months following the Atoms for Peace Conference and the release of information on fusion work it has been the task of physicists everywhere to reflect on the conclusions to be drawn from the impressive display of apparatus and ideas that was so suddenly revealed to them. Before any programme of fusion research can be seriously discussed, it is very important to define the nature of the work that has to be done in the near future. The Study Group discussed this problem in the second meeting and the following is a résumé of the points brought out in these discussions.

One cannot escape the conclusion that much of the work done previous to the 1958 Atoms for Peace Conference was inspired by the hope of achieving a quick break-through in the problem of producing a fusion reactor and that the devices conceived and built were chosen because they might lead to a possible reactor. This technique of tackling a scientific problem, which has often succeeded in the past, assumes that concurrently with building large scale projects, solutions will be found to the more fundamental problems and that the two activities will progress together at roughly the same speed.

It seems to be a general conclusion that this state of affairs has not come about and that the fundamental physics, on which all devices and projects depend, has proved to be much more intractable than was originally estimated.

It is therefore clear that the major task before everyone engaged in fusion work in the near future is to accelerate the understanding of the physics of plasma.

However, such a conclusion does not imply that large scale experimental work should be abandoned, nor does it mean a slowing down of fusion activities. A properly balanced programme must allow for the study of fusion problems, theoretical, experimental and technological, on as broad a front as is economically possible. Small university research teams, large national groups and industrial development groups all have an essential part to play in the fusion programme. It is inevitable that the large scale experiments will be carried out in those laboratories where adequate facilities, particularly energy storage systems, can be built up on an appropriate scale, and it is worth bearing in mind that these experiments may well be as large as any of the devices described at the Geneva Conference.

A European fusion programme should aim at encouraging this diverse activity at all levels and by whatever means that are appropriate.

Looking at the programmes of work of the European laboratories listed above, one is impressed by the fact that there is a general coverage of the different aspects of the fusion problem with remarkably little concentration by several laboratories on one problem. This is a very healthy state of affairs and to some extent has emerged from the discussions in the Study Group meeting which have enabled laboratories to arrange their programmes in the light of the work of other laboratories. The major divisions of the problem, namely toroidal pinch, mirror confinement and Stellarator confinement, form the central programmes of the three largest national laboratory groups, respectively British, French and German. Other problems are being tackled either by the large laboratories or by smaller centres or by university laboratories.

2. On the magnitude of the effort on fusion problems in Europe

There is no absolute scale by which to decide whether or not Europe is putting enough effort into the fusion problem. It was stated at the Atoms for Peace Conference that it may well take twenty or more years to make a fusion reactor. However, fusion reactors, if they are possible at all, do in principle

offer advantages over other energy producing methods and these advantages have been thought sufficient by the USA and USSR to justify a considerable effort on fusion research. Also it should be borne in mind that other important applications of plasma physics may be discovered in the course of the fusion work.

The Study Group, in considering this problem, listed the planned effort on fusion research in the various European laboratories for 1958 and 1959 in order to compare this effort with that existing and planned in the USA. In making the comparison only the larger national groups have been recorded by name. The smaller laboratories are grouped together in order to make a comparison with the AEC effort. The record is made in terms of scientific staff and operating costs.

Laboratories	Calendar Year 1958 Scientific Staff	1958 Operating Costs M $	1959 Scientific Staff	1959 Operating Costs M $
Britain				
AERE, AWRE, AEI	120	3	150	6
France				
CEA	31	0.8	60	2.5
Germany				
Munich, Aachen	65	1.2	110	2.0
Other European Laboratories	-	1.7	-	2.4
Totals :	216	6.7	320	12.9

The corresponding figures for the AEC fusion programme are:

Laboratories	Calendar Year 1958 Scientific Staff	1958 Operating Costs M $	1959 Scientific Staff	1959 Operating Costs M $
Los Alamos	38	3.3	40	4.6
Oak Ridge	70	4.9	99	6.7
Princeton	97	12.0*	115	16.8*
Livermore	83	6.7	93	7.4
Other Laboratories	-	1.8	-	2.5
Totals	288	28.7	347	38.0

*Model C Stellarator fabrication costs: 7.2 M $ in 1958 and 10.6 M $ in 1959.

Although the figures for the European laboratories are approximate, it is nevertheless possible to see that the number of scientific staff working on fusion problems in 1959 in Europe is comparable with the corresponding staff numbers in the USA. On the other hand, the European operating costs for fusion research are but a small fraction of those of the USA.

In trying to understand these results many factors have to be taken into account. Whereas the American groups have been working on fusion problems for several years, most of the European groups are relatively new in the field. It is known that new groups need some ti e to establish themselves and their programmes before spendin, large sums of money. The tendency in the European centres is to concentrate their efforts on smaller experimental devices than the comparable American centres, and so spend less money on capital equipment. For example, the Stellarator C Project accounts for 17.6 M $ in the two years 1958, 1959, and there is nothing comparable with this planned so far in Europe. Another factor noticeable in Europe is the number of smaller laboratories engaged in fusion work. Although their operating costs are small the numbers of scientific staff in these laboratories add up to nearly half the total staff in the larger centres (the exact figures are: Scientific Staff in other laboratories - 1958: 95, 1959: 154). It may be that in giving their operating costs the European groups have underestimated.

However, taking all these points into consideration, the Study Group were at a loss to explain the very large differences in the operating costs between American and European centres. It would be well worth while repeating this exercise in a year's time.

3. On the problem of the education and training of staff and the exchange of staff between laboratories

The sudden preoccupation of European countries in fusion problems creates a serious problem of finding staff for the programmes, particularly scientific staff. Staff already familiar with plasma physics can only come from the astrophysics institutes or from those universities already occupied with academic research in plasma physics. These institutes and laboratories, which are small in number, will obviously continue with their own problems and only a small fraction of their staff will be available for fusion work. Thus the supply of scientific staff already familiar with plasma physics is small. In addition to this staff

there is also need of scientific staff familiar with many other branches of physics, such as spectroscopy, microwave techniques, nuclear physics, and all those techniques associated with particle accelerator machines. The growth of activity in high energy nuclear physics in Europe since 1950 has led to the formation of powerful groups of physicists and engineers well trained in accelerator physics and above all familiar with large scale project work. Such people, if and when they become available, will be invaluable to the European fusion programmes. With the other branches of physics involved there should be no real shortage of staff, provided that the interest of such people in fusion problems is aroused and maintained.

The staffing problem in fusion research is not fundamentally different from the problem of finding staff for the other branches of physics. There is undoubtedly a serious shortage of physicists in Europe, and plasma physics and fusion research can only take a fraction of these people. The first need, therefore, is to train more physicists, and the special problem for the fusion groups is to interest a reasonable fraction of these people in plasma physics. Those universities where the professors and lecturers are themselves interested in the subject, and where lectures and research in plasma physics are actively undertaken, are clearly most likely to turn out the largest number of young physicists interested in fusion research. It seems from the discussions in the Study Group that there are now several universities already established in this field, for example Uppsala, Stockholm, Aachen, Munich, London etc.

Another way in which interest can be aroused is by special courses in plasma physics and fusion, such as are already run at Saclay and Munich. Saclay (CEA) has arranged courses extending over five months for graduates, and similar courses exist at Munich (Astrophysics Institute). In addition a summer school for fusion problems is being arranged in 1959 by the Italian Physics Society at Varenna. All these courses are open to any European physicists who want to take part and who are accepted by the centres running the courses.

Clearly this type of training is of immense value in making physicists familiar with the problems of plasma physics and should be supported and encouraged to the full.

Another important question discussed by the Study Group concerns the exchange of staff working on fusion problems between the various laboratories. Now that there are no longer any questions of security or classification in fusion work, the problem is only one of arranging that European staff can move freely between the laboratories.

The reasons why such an exchange of staff is desirable need stating. In the first place there are many groups in Europe that will not have available large facilities with which their staff can pursue experiments started on a smaller scale. It is to their advantage to send their staff for a time to centres where these facilities exist. Secondly there is clearly a shortage of staff familiar with this branch of physics and it is in the interest of the larger centres to have as guests senior staff from other centres or from smaller laboratories. Lastly it is in the common interest of all the European laboratories to profit by the experience of other laboratories and this can very well be done by allowing scientific staff to work in other laboratories than their own.

Such exchange schemes are already an established tradition in the Max-Planck-Institutes of Germany, and it is an accepted way of life in high energy physics. At CERN, for example, where facilities for high energy physics exist, a system of CERN fellowships, research associateships and FORD fellowships enables physicists from all over the world to spend a year or more at CERN working on high energy physics problems. Also there are many guests not paid by CERN grants, but working at CERN with grants paid by their own institutes.

4. On the subject of national and international laboratories for fusion problems

One of the ways in which fusion work in Europe might be facilitated is by setting up a European laboratory for fusion problems, and this idea was considered by the Study Group.

It should be made clear that the Study Group did not consider any idea of a European laboratory for fusion problems that would replace the national laboratories. The problem considered was only if there was a need for such a laboratory in addition to those already existing. Also the Study Group did not concern itself with the way in which such a laboratory could be set up.

The advantages of such a European laboratory can be stated as follows:

a) It could build up larger facilities than would be possible in a national laboratory.

b) It could act as a centre for fusion work in the sense that conferences, exchange of staff between laboratories, training of staff, exchange of reports etc. could be arranged by such a laboratory.

c) It could act as a centre for contacts with USA and USSR on fusion work.

d) It could help the smaller national centres and university laboratories in fusion problems.

Some disadvantages are the following:

a) It may take staff and money away from the national laboratories at a time when they were trying to expand their activities.

b) At the present time the national laboratories can manage the fusion programme themselves and build sufficiently large facilities for the immediate future.

It was felt by the Study Group that unless it can be demonstrated that a European laboratory is needed in order to build larger facilities than can be built by national groups, the many other advantages of such a centre may prove insufficient to overcome the difficulties in its creation and maintenance.

The facilities, often mentioned in this report, which can be compared with accelerating machine facilities for high energy physics, need to be specified. By far the largest expense in the work on fusion is in setting up the energy storage system, the diagnostic techniques and the general laboratory technology and services. It has been mentioned that Britain is planning to set up a fairly large energy storage system consisting of condenser banks, rotating machines, inductive storage and batteries with all the necessary switching plant. This system is comparable with the Princeton energy storage for Stellarator C now in course of construction and will cost about 20 M £ over about four years. Such an energy store is useful for fusion devices using magnetic confinement and, if it is sufficiently flexible, does not commit the laboratory to one device or line of approach. No comparable plan for an energy store has been announced by any other European group. Also the energy store is by no means the only expensive part of the facilities used for fusion work.

The Study Group therefore considered whether another similar or larger facility of this kind could be justified in Europe, which might then be considered as the raison d'être of a European laboratory. There was no clear unanimity in the views

expressed by the different members of the Study Group. The British group considered that their facility could be justified, but this did not enable them to justify another similar or larger one in a central laboratory. The German groups in general did not see the need for the Stellarator C installation at the moment and preferred to work on a smaller scale, although they are making plans to expand the present energy storage system if the need arises. The French groups expressed a similar opinion; they felt that although the immediate building of a large scale store is perhaps premature, it is advisable to make studies right away, especially considering the long time needed for the study and for completion of the installation. The matter was therefore left for a later review of the whole problem.

The part being played by EURATOM in the fusion work was discussed by the Study Group. EURATOM represents five of the twelve member states of CERN and does not contain the most currently active member state in the work on fusion, namely Britain. The policy of EURATOM on fusion is to encourage the growth of large centres in its member states by placing contracts for fusion work. They plan to place a contract with Saclay (CEA) and possibly Munich with this aim in mind. Their policy does not exclude other countries than the six EURATOM countries from joining in this work. They have at their disposal about 10 M $ in the next four years, and this sum of money can be increased if the need arises. They also plan to set up a central laboratory for fusion work if this is shown to be necessary. Their general policy is to concentrate the fusion work in order to counteract the dispersion tendency. They are offering 5 or 6 scholarships to the Saclay fusion courses this year and 8 scholarships at Munich in order to help with the training of staff.

Some of the members of the Study Group expressed concern that no central organization available to them existed for fusion research.

In America the policy with regard to fusion work seems to have been to let the laboratories financed by the AEC choose their own programmes within wide limits. However, behind all these laboratories there has been the general organization of the AEC forming a backbone to the whole venture. In Europe on the other hand there is no such common organization although the large national centres can be compared with the AEC laboratories in the States.

With the work of the Study Group coming to an end, there does seem to be a need for some centre to continue the initiative shown by CERN in setting up the Study Group.

5. On the exchange of information between European laboratories and with those of the USA and USSR

To take again the example of high energy physics, it has been the practice for several years now for each laboratory to issue its own series of reports and to distribute them to all other laboratories working in the field. These reports are in a sense interim and do not have the same status as publications in scientific journals. Nevertheless their circulation has been, as it were, the life blood of the high energy physics organism. It has been the function of the libraries in the various laboratories to arrange exchange schemes for these reports and nowadays the whole system is highly efficient and extremely valuable.

No such system exists generally as yet for fusion research although there is now no reason why it could not be set up. Nearly all the laboratories are equipped with reproduction facilities and are used to issuing these reports in other fields. For a healthy situation to exist it is very important to establish this exchange of information as soon as possible.

CERN has already set up an exchange scheme with the AEC for fusion reports as an extension of its normal exchange scheme for other reports, and these are now becoming available in the CERN library as they are declassified in the States. If the laboratories cannot arrange their own exchange scheme with the AEC, they could obtain the reports from CERN. It has been made clear by the AEC that it is very convenient for them to have as small a number of exchange libraries as possible in Europe. CERN also has an exchange scheme working for nuclear physics publications with the Russian laboratory at Dubna. So far this scheme has not been extended to fusion reports although this could perhaps be arranged. There exists a real need for a translation service for Russian reports. This does not necessarily mean setting up a new service since one already exists in the USA. It would suffice that European laboratories could have copies from such a service.

Part IV. Recommendations of the Study Group

It seems fitting that the Study Group should end its report with specific recommendations covering the objectives that it was asked to consider. These recommendations, which, the Study Group hopes, will be seriously considered by those national and international organizations that are interested in the problem of fusion research and development in Europe, are listed below with brief commentaries on each.

1. There should be set up a regular review of the European programmes for fusion research

It has been mentioned many times in this report that the plans of the European laboratories are very tentative and many groups are only just being formed. Also it has been pointed out that the investment programme in Europe seems to fall short of the American programme by a large factor, and the staff plans may be difficult to realize in practice. For all these reasons a regular review of the situation would be of general interest.

In particular the question of the creation of a European laboratory should be reviewed in a year's time, to see whether such a centre is then needed. There seems little doubt that a central organization could help immediately with many problems, but until it is shown that it can play a vital role in the European development of fusion that cannot be played by the larger national centres, such as establishing more extensive facilities for fusion research, the difficulties in setting it up may prove insuperable.

2. There should be set up regular scientific discussion meetings, to be held in rotation at the main European laboratories working on fusion problems

In the USA the six-monthly AEC fusion meetings have proved to be most valuable, and something similar is required in Europe. The attendance at these meetings should be limited to about sixty people, and they should be discussion meetings, not large conferences. The Study Group has spent at least half of its time discussing general and specific fusion problems, and it is agreed that this has been extremely useful, especially for the newer groups in this field. The size of the Study Group is about thirty people and twice this size would be a maximum for a discussion meeting.

3. Encouragement should be given to schemes by which staff can work at other laboratories apart from their own.

The reasons for this recommendation have already been explained at length above (see III. 3).

4. Particular attention should be paid by all laboratories and national institutes to the training of staff and the education of graduates in the universities

This point has been dealt with under (III. 3) above.

5. Laboratories should set up as soon as possible exchange schemes for reports on fusion problems

6. Close collaboration should be maintained with the laboratories in the USA and USSR, and exchange schemes for reports set up

This point has been dealt with under (III. 5) above. It has been most useful for the Study Group to have as a member Dr. Amasa S. Bishop who has been so closely connected with the AEC programmes. Also Dr. Arthur E. Ruark, the present Chief of the Controlled Thermonuclear Branch of the AEC Division of Research, has been keenly interested in the work of the Study Group and has greatly helped in making immediately available declassified reports of Project Sherwood to the CERN library. Both Dr. Bishop and Dr. Ruark have expressed the wish for close co-operation between the AEC and European fusion work in the future. Through some common organization this problem would be simple, but it is no doubt difficult for the AEC to maintain close contact with up to thirty separate laboratories in Europe.

Part V. Proposals of the Study Group

In considering the draft of this report, which ended with the Recommendations given above in Part IV, the Study Group thought it advisable to make proposals on how such recommendations might be realized in practice.

The Study Group was set up by CERN, in whose Council are represented the twelve European member states. Although the members of the Study Group could no doubt go on meeting as a scientific body, this link with the Governments, now provided by the Council of CERN, would be lost should CERN withdraw its support at the termination of the present task, and the Study Group felt that some formal access to the European Governments was essential.

Three proposals covering these points are put forward by the Study Group.

1. That CERN be asked to continue its sponsorship and support of the Study Group

The majority of the members of the Study Group preferred this solution and the advantages are obvious enough. However, it was recognized that although CERN set up the Study Group, its Council might feel that, since fusion research did not form part of the programme of CERN, it could not continue to sponsor the Study Group in the future. To cover this eventuality two other proposals were suggested.

2. That a new Society be set up to continue the work of the Study Group

Again the majority of the members of the Study Group were in favour of proposing that a new Society be set up to continue the work of the Study Group should CERN withdraw its support. There already exists in Europe a Society called the European Atomic Energy Society, whose aims and objectives are very similar in the field of fission to the recommendations listed above for fusion research. Consequently, the Statutes of the E.A.E.S. were modified to suit the needs of fusion research and are presented in Appendix I as suggested statutes for a European Society for Controlled Thermonuclear Research. The recommendations of the Study Group appear as the aims of this new Society.

3. That the European Atomic Energy Society be asked to expand its aims and interests to cover fusion research

A small minority of the members of the Study Group preferred that, instead of setting up a new Society, the E.A.E.S. be asked to expand its aims and interests to cover fusion research. This is a possible solution, but not one preferred by the majority of the members of the Study Group who felt that, failing the support of CERN, it would be better to set up a new Society with the problems of fusion as its sole interest.

Enc. Appendix I

EUROPEAN SOCIETY FOR CONTROLLED THERMONUCLEAR RESEARCH

STATUTES

I. Aims of the Society

The main aim of the Society is to promote co-operation in controlled thermonuclear research and development. To achieve this aim the Society will:

a) Arrange regular international meetings of scientists and engineers working in the field of controlled thermonuclear research and development.

b) Promote the circulation of reports and other information between European laboratories.

c) Promote the exchange of information and reports with other countries outside Europe and, if possible, establish a centre of information for such reports somewhere in Europe.

d) Establish a centre of information on the availability of equipment and materials for C.T.R. work.

e) Promote the exchange of staff between laboratories engaged in C.T.R. work.

II. Membership

1. The founding of this Society is suggested by the "CERN Study Group on Fusion Problems", a list of whose members is given in Part I, Section 3 of the "Report of the CERN Study Group on Fusion Problems".

2. Invitations to join the Society may be issued by the Council (see Section III) to European laboratories which, in its opinion, have established controlled thermonuclear projects. In each country the invitation is to be sent to the Agency recognized by its Government to be the central agency for controlled thermonuclear research. If no such agency exists, the invitation can be

sent to any organization recognized by the Government as entitled to represent the country in the Society. Invitations to join the Society can only be issued if the invitation is approved by unanimous decision of the Council and this provision of the Statutes can only be altered by the unanimous decision of the complete Council.

3. The Council can institute Associate Membership for countries outside Europe and for countries without established thermonuclear projects.

III. Administration

1. The work of the Society shall be directed by a Council. The Council will consist of one Delegate appointed by each Member. In all matters requiring a vote, each Delegate will have one vote.

2. There will be a Working Group to conduct the business of the Society between meetings of the Council. Each Member will nominate a Delegate to the Working Group.

3. The Council will, from its Delegates, elect annually a President, an Executive Vice-President and one or more Vice-Presidents as may be thought desirable. The Executive Vice-President will be Chairman of the Working Group.

4. The Secretariat of the Society will be provided by the Chairman of the Working Group.

5. The Council may formulate Bye-Laws on any matters not covered by these Statutes.

IV. Meetings of the Council

Council Meetings will be called by the President, or, in his absence, the Executive Vice-President. The Council will normally meet once a year. The President must call a meeting of the Council if so requested by at least one third of the Members.

V. Finances

The Members will cover current expenses incurred in connection with their work in and for the Society.

VI. Modifications to the Statutes

Any Member wishing to propose changes in these Statutes shall notify the Secretariat at least three months before a Council Meeting. Notice of proposed changes in the Statutes shall be sent to the Members at least one month before a Council Meeting. No change shall be made in the Statutes except at a Council Meeting and with the approval of at least two thirds of the Delegates, subject to the reservations made in Section II, paragraph 2.

Controlled Fusion in the United Kingdom

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STAFF NOTE.—Information on the United Kingdom fusion program appeared as paragraph 40 of the report submitted in response to a request by Senator Anderson. This paragraph is as follows:

The study of fusion reactions in the United Kingdom, as in other countries, has not yet reached a stage when any prediction can be made about their application. The Authority have under construction a further experiment in succession to the former Zeta experiment, known as the Intermediate Current Stability Experiment (ICSE). This is intended for a study of some of the phenomena encountered in Zeta as a contribution to the long-term objective of achieving or identifying a net yield of thermonuclear neutrons.

Controlled Fusion in the U.S.S.R.

STAFF NOTE.—Similar fusion program information was sought from the Soviet Union, but no response was forthcoming. Pertinent correspondence in this regard appears in the background information section relating to atomic power.

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